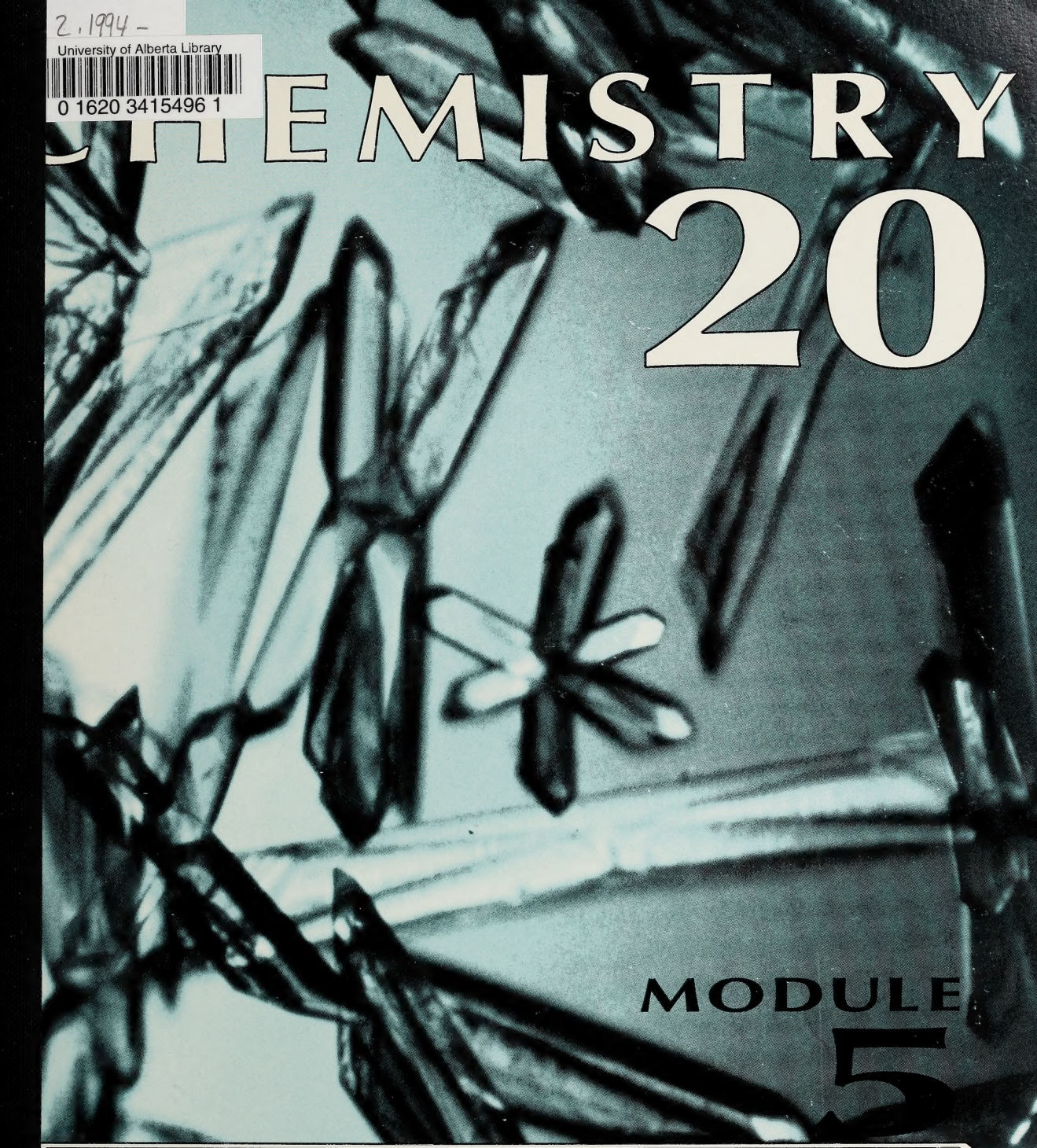
2.1994 -
University of Alberta Library
0 1620 3415496 1

CHEMISTRY 20



MODULE 5

CHEMICAL BONDING

Distance Learning

Alberta EDUCATION

Digitized by the Internet Archive
in 2017 with funding from
University of Alberta Libraries

https://archive.org/details/chemistry2005albe_1

JUL 2 6 1994

Chemistry 20

Module 5

Chemical Bonding

Distance Learning

Alberta EDUCATION

IT IS STRICTLY PROHIBITED TO COPY ANY PART OF THESE MATERIALS UNDER THE TERMS OF A LICENCE FROM A COLLECTIVE OR A LICENSING BODY.

This document is intended for	
Students	✓
Teachers (Chemistry 20)	✓
Administrators	
Parents	
General Public	
Other	

Chemistry 20
Student Module
Module 5
Chemical Bonding
Alberta Distance Learning Centre
ISBN No. 0-7741-0900-9

Cover Photo: NASA

ALL RIGHTS RESERVED

Copyright © 1993, the Crown in Right of Alberta, as represented by the Minister of Education, Alberta Education, 11160 Jasper Avenue, Edmonton, Alberta, T5K 0L2. All rights reserved. Additional copies may be obtained from the Learning Resources Distributing Centre.

No part of this courseware may be reproduced in any form, including photocopying (unless otherwise indicated), without the written permission of Alberta Education.

Every effort has been made both to provide proper acknowledgement of the original source and to comply with copyright law. If cases are identified where this has not been done, please notify Alberta Education so appropriate corrective action can be taken.

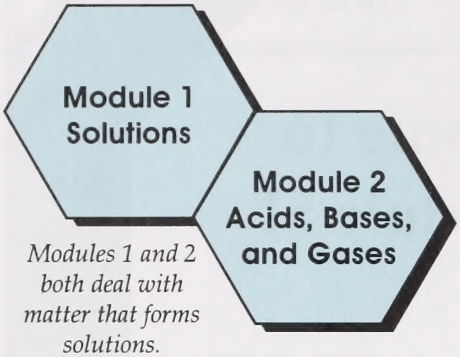
UNIVERSITY LIBRARY

Welcome to Module 5!

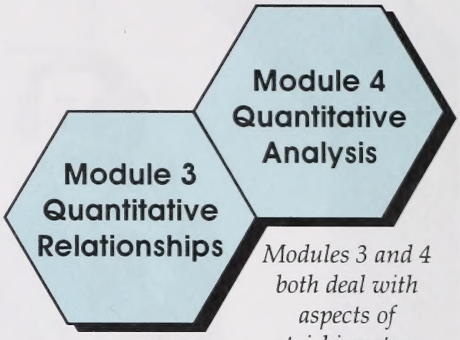
We hope you'll enjoy your study of *Chemical Bonding*. Remember, to make your learning a bit easier, several videocassettes and laser videodiscs are referred to throughout the modules. Your textbook *Nelson Chemistry* will also enhance your studies.

COURSE OVERVIEW

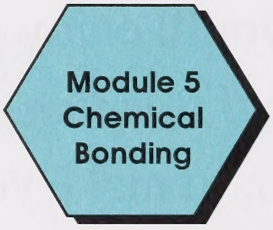
This course contains seven modules. The module you are working in is highlighted in deeper colour.

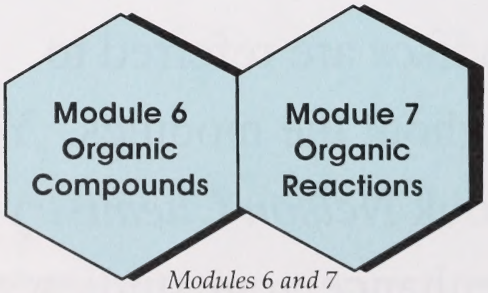


Modules 1 and 2 both deal with matter that forms solutions.



Modules 3 and 4 both deal with aspects of stoichiometry.





Modules 6 and 7 both deal with organic chemistry.

MODULE 5

Contents

Module Overview 1
Evaluation 2

Section 1: The Basics of Bonds 3

Activity 1: Patterns in Reactions 4
Activity 2: Periodicity Revisited 8
Activity 3: Chemical Bonds 15
Follow-up Activities 21
Extra Help 21
Enrichment 23
Conclusion 24
Assignment 24

Section 2: Ionic Bonding 27

Activity 1: What Does Being Ionic Mean? 28
Activity 2: Ionic Compound Formation 31
Activity 3: Ionic Models 40
Follow-up Activities 46
Extra Help 47
Enrichment 49
Conclusion 50
Assignment 50

Section 3: Molecular Bonding 52

Activity 1: Is This Substance Molecular? 53
Activity 2: Molecular Models 59
Follow-up Activities 67
Extra Help 67
Enrichment 69
Conclusion 70
Assignment 70

MODULE 5

Contents

Continued

Section 4: Bond Strength and Applications 72

Activity 1: Bond Energy and Strength 73
Activity 2: Intermolecular Forces 77
Activity 3: Technology and Applications 85
Follow-up Activities 90
Extra Help 91
Enrichment 93
Conclusion 94
Assignment 94

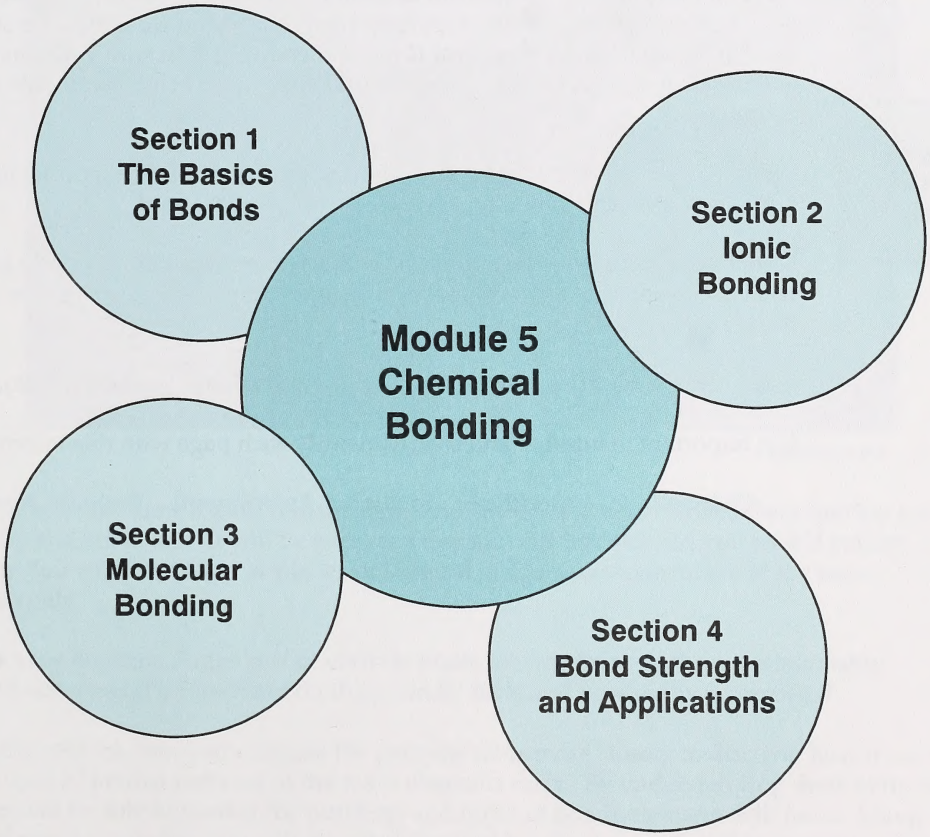
Module Summary 96

Appendix 97
Glossary 98
Suggested Answers 100

MODULE OVERVIEW

The world around you is filled with an endless variety of materials. There are numerous hard and soft metals refined to make such things as parts for airplanes and flexible wires for electrical circuits. There are diamonds that amaze you with their brilliance and hardness and many different plastic products with various degrees of flexibility and strength. But have you ever wondered what holds all these materials together? Why does it take so much effort to break some materials and others very little effort? Is there a common attraction that holds each of these materials together or do they stick together for different reasons?

In this module, you will explore what makes atoms stick together. You will examine the bonding properties of a variety of different materials and learn how scientists use these properties to advance technology. You will see bonding knowledge applied to a number of different situations and hopefully gain a better understanding of bonding principles.



Evaluation

Your mark in this module will be determined by how well you complete the assignments at the end of each section. You must complete all assignments. In this module you are expected to complete four assignments. The mark distribution is as follows:

Section 1 Assignment	**30 marks**
Section 2 Assignment	**25 marks**
Section 3 Assignment	**20 marks**
Section 4 Assignment	**25 marks**
TOTAL	**100 marks**

When doing your assignments, work slowly and carefully. If you are having difficulties, go back and review the appropriate section.

Read all parts of your assignment carefully. Plan and do your rough work on your own paper. Revise and edit your responses; then set up your final copy for submission on your own paper. Lined looseleaf is recommended. Make sure your answers are neat and organized, with wide left margins and space for teacher comments after each assignment.

When you see this icon, ideas and details are provided to help you set up and organize your answer in a certain way.

Before submitting your responses, be sure to proofread them carefully to ensure they say what you want, that they are neat and clear, and that they are complete and missing no material.

You will be submitting **only** your **assignment response pages** for evaluation.

It is important to number and clearly identify each page with this information at the top.

Chemistry 20 – Module 5 Section # Assignment Page # Name and ID #

SECTION 1

The Basics of Bonds

NASA

WESTFILE INC.

Why is it that some metals remain shiny and smooth for years while others quickly get rusty and fall apart? If you've ever seen a rusted old truck or car, you would realize why you wouldn't want airplanes or surgical instruments to be made of the same materials.

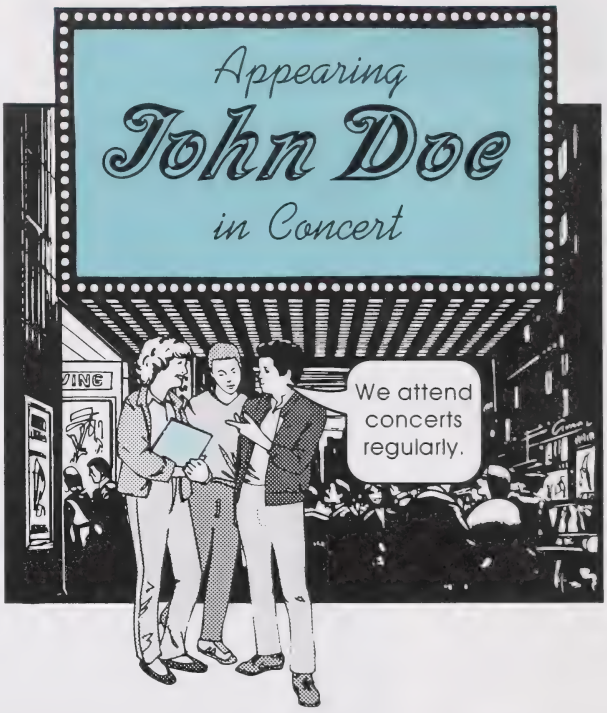
But why do some things rust or corrode while others don't? Is there a relationship between a metal's placement on the periodic table and how easily it corrodes?

In this section, you will examine the periodic table more closely to discover how it can be used to predict patterns in the ways elements react. By understanding these patterns you will be able to predict the numbers and types of bonds elements will form. Using this new knowledge, you will see why chemical bonds are significant in your daily lives.

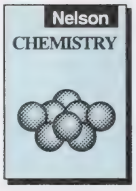
ACTIVITY

1 Patterns in Reactions

When people say they attend concerts periodically, you know it means that they attend concerts from time to time.

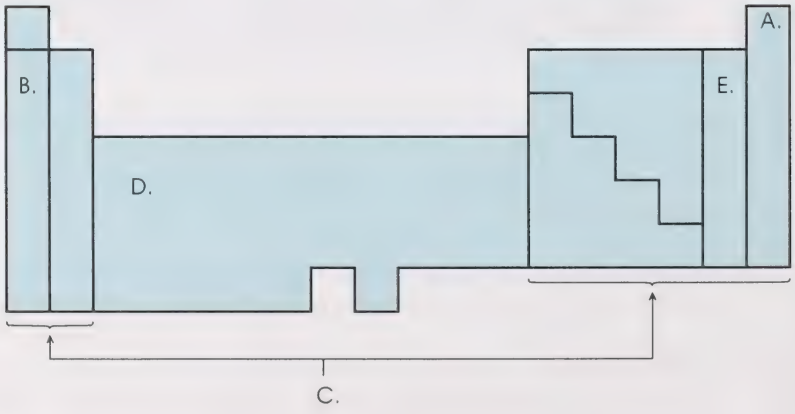


You have learned that the periodic table gets its name from the fact that certain patterns repeat themselves at regular intervals as the elements increase in atomic number.



To review these concepts, read the section, The Modern Periodic Table, on pages 52 to 55 in *Nelson Chemistry*. Pay special attention to the groups and series of elements. To help you remember some of the important features of the periodic table, do the following questions.

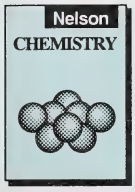
1. Match each of the letters from the following periodic table to its appropriate name.



- transition metals
- halogens
- alkali metals
- noble gases
- representative elements

2. What are some common properties of the members of the alkali metal family?

3. A horizontal row on the periodic table is called a _____.



Aside from the parts of the periodic table, you should also notice that as you proceed across the periodic table, trends in chemical reactions are often observed. To examine the nature of **periodicity** more closely, read the top one-half of page 203 in *Nelson Chemistry*. Use the information to answer the following questions.

periodicity – regularly repeating properties of the elements as the atomic number increases

family – a vertical column on the periodic table

4. Examine Table 8.1 on page 203 of your textbook.

   a. Within a **family**, identify the similarity you observe in the chemical formulas.

   b. If cesium were to react with fluorine, what would you expect the chemical formula to be? Why?

5. Why are elements arranged in chemical families?

6. In your own words, what is an activity series?

Check your answers by turning to the Appendix, Section 1: Activity 1.

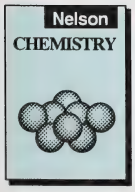
In the section introduction, the question was posed concerning the relationship between the position of a metal on the periodic table and how easily it corrodes. Is there a pattern to the reactivity of metals? You are now ready to perform an experiment that will answer this question through the development of an activity series.

Investigation 8.1: Activity Series

PATHWAYS

If you have access to laboratory facilities, do Part A.
If you do not have access to laboratory facilities, do Part B.

Part A



Carefully follow the directions given for Investigation 8.1 on page 203 of your textbook. Pay special attention to the required components, safety aspects, and applied science skills.

Guidelines

Science Skills
- [x] A. Initiating
- [x] B. Collecting
- [x] C. Organizing
- [x] D. Analysing
- [ ] E. Synthesizing
- [x] F. Evaluating

- The dilute hydrochloric acid should be 1.0 mol/L $HCl_{(aq)}$.
- Use pieces of metal approximately 0.5-1.0 cm in length.

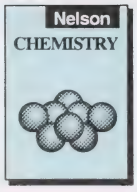
7. Write a brief description of your design.
8. Make a list of your materials.
9. Outline your procedure in point form.
10. Record your evidence in a data table.

You will complete your analysis after Part B.

Check your answers by turning to the Appendix, Section 1: Activity 1.

End of Part A

Part B



Carefully read the directions given for Investigation 8.1 on page 203 of your textbook. Pay special attention to the required components, safety aspects, and applied science skills.

Keep the following in mind.

Guidelines

Science Skills
- [x] A. Initiating
- [x] B. Collecting
- [x] C. Organizing
- [x] D. Analysing
- [ ] E. Synthesizing
- [x] F. Evaluating

- Since 1.0 mol/L $HCl_{(aq)}$ is not available, you will need to carry out the investigation using 0.10 mol/L $HCl_{(aq)}$.
- Not all the metals will react with 0.10 mol/L $HCl_{(aq)}$ and calcium metal may not be available. Therefore, you will need to refer to the Appendix (as described in question 14 following) for evidence of the reactions that you were unable to obtain.

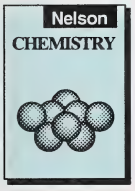
11. Write a brief description of your design.
12. Make a list of your materials.
13. Outline your procedure in point form.

14. Record your evidence in a data table. Copy evidence of reactions that you were unable to obtain by referring to the answer for question 10, Section 1, Activity 1 in the Appendix.

Check your answers by turning to the Appendix, Section 1: Activity 1.

End of Part B

Analysis



15. a. To complete your analysis for Investigation 8.1, answer the investigation problem as given in your textbook (page 203).

    b. Account for any discrepancies that may have occurred in your results.

16. Make a generalization that explains how metals react with acids as you proceed from left to right across the periodic table.

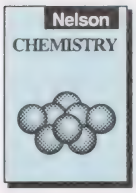
Check your answers by turning to the Appendix, Section 1: Activity 1.

NASA

corrosion – the loss of electrons by a metal when it reacts with moist air

oxide – the product of a reaction between a metal and oxygen

Have you ever wondered why the aluminum on planes and buildings doesn't appear to rust or corrode like the iron on cars? The aluminum actually does corrode in a similar process, but the aluminum **corrosion** produces an **oxide** that is not as visible as the iron's oxide or rust. You can see the oxide coating on aluminum if you rub the aluminum – your hand gets black.



To examine the trends of oxide reactivity as you proceed across the periodic table, read Lab Exercise 8A: Metal and Nonmetal Oxides on pages 203 and 204 of your textbook. Complete the analysis by answering the following question.

Science Skills

- [ ] A. Initiating
- [ ] B. Collecting
- [ ] C. Organizing
- [x] D. Analysing
- [x] E. Synthesizing
- [x] F. Evaluating

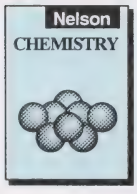
17. a. As you proceed from left to right across the third period of the periodic table, describe what happens to the acidic and basic properties of the oxides of the elements.

    b. How do the trends in Lab Exercise 8A compare to the trends in the results obtained in Investigation 8.1?

Now that you have had a chance to examine the patterns of some of the elements within the periodic table, read the rest of page 204 and the top of page 205. This will summarize some of the general reactivity trends found on the periodic table. Use this information to answer the next two questions.

18. a. When metals react with nonmetals, what type of substance is formed?

    b. How can you distinguish between an ionic compound and a molecular compound?



19. Examine Figure 8.2 on page 204 in your textbook.

    a. What two families of the periodic table are most reactive?

    b. What two regions of the periodic table are generally least reactive?

Check your answers by turning to the Appendix, Section 1: Activity 1.

In this activity you have reviewed some of the basic aspects of the periodic table and observed some of the trends in reactivity for the elements on this table. The important thing to remember is that the trends are general ones that can be represented diagrammatically as in Figure 8.2 on page 204 of your textbook.

ACTIVITY 2

Periodicity Revisited

valence electron – the electrons in the outermost energy level of an atom

In Activity 1, you learned about several reactivity trends and how they relate to trends on the periodic table. But how do you explain these trends?

Elements within the same chemical family have similar chemical properties because they have the same number of valence electrons. It is these outer energy electrons that are involved in chemical bonding and chemical reactions.

AOSTRA

1. In what two basic ways can electrons be involved in bonding?

Bohr model – a representation that shows small negatively charged electrons circling a positively-charged nucleus in discrete energy levels similar to the way the planets orbit the sun

The following Bohr model of an atom shows where the valence electrons are located.

Note: In modern atomic theory, electrons do not orbit the nucleus. Instead, they are found in regions of space called orbitals around the nucleus. The valence electrons are in the outermost space (highest energy level).

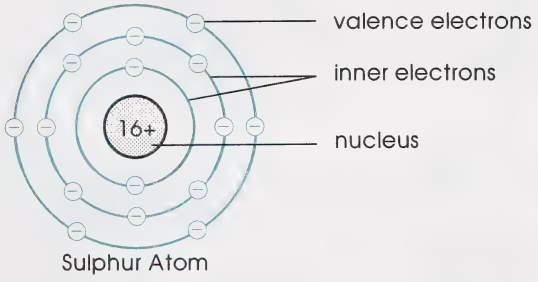
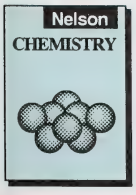


FIGURE 5.1: The Bohr Model of a Sulphur Atom



group – a vertical column on the periodic table

The number of outer energy electrons or valence electrons can be determined for the representative elements (Group A elements) by using the periodic table. Look at the periodic table inside the front cover of your textbook. You will notice that the columns or families are numbered in two ways – by numbers and by roman numerals and letters. You should be familiar with both methods of numbering. The newer method is the simple number method (1, 2, etc.). The number of valence electrons in an atom of a representative element is the same as the last digit of the group number, using the simple numbering system, or the Group A numbers, using the roman numeral system.

Group Number	1	2	13	14	15	16	17	18
	IA	IIA	IIIA	IVA	VA	VIA	VIIA	VIIIA
Number of Valence Electrons	1	2	3	4	5	6	7	8

The valence electrons of transition elements (Group B elements) cannot be readily determined using group numbers and do not show the typical valence electron pattern. Therefore, you will only be required to determine the valence electrons for representative elements.

2. a. If a particular element has five valence electrons, then its group number is _____.

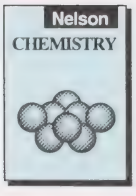
   b. The maximum number of valence electrons a representative element can have is _____.

3. Give the number of valence electrons that each of the following elements will have.

   a. magnesium
   b. silicon
   c. oxygen
   d. lithium
   e. aluminum
   f. nitrogen
   g. argon
   h. iodine
   i. helium

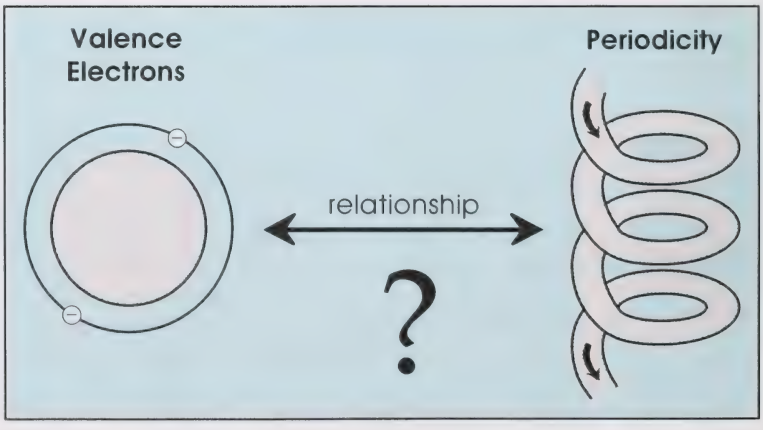
Check your answers by turning to the Appendix, Section 1: Activity 2.

You now know how to find the number of valence electrons an element has, but what rules do these electrons follow that explain the periodicity of the chemical properties of the elements?



Read the section Understanding Chemical Periodicity on pages 205-206 (to the section on Lewis models).

To summarize the main points about what you read, answer the following questions.



4. a. What is a valence orbital?

   b. How many valence orbitals does each representative element have?

5. What is the maximum number of electrons any single orbital can have?

6. Why do electrons half fill all the empty valence orbitals before they begin to pair up?

7. Single valence electrons are called _____ while paired valence electrons are called _____.

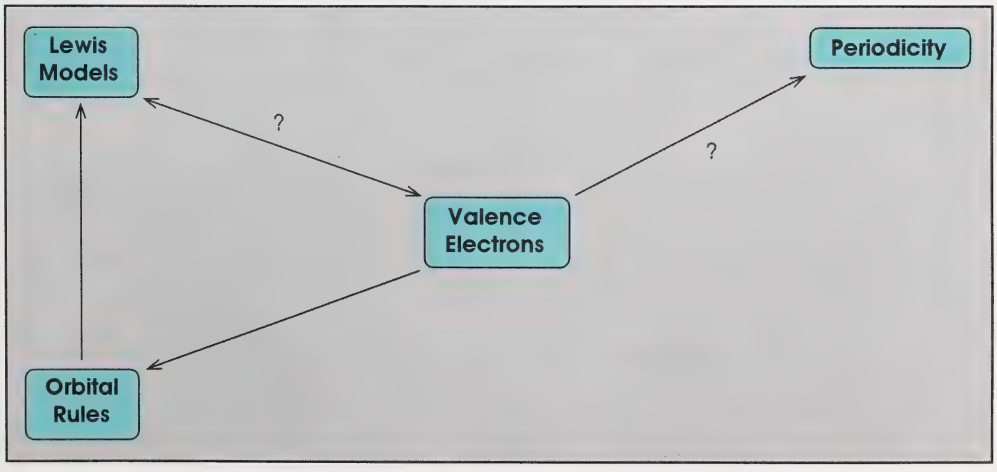
Check your answers by turning to the Appendix, Section 1: Activity 2.

If you try to explain the positions and properties of valence electrons using Bohr diagrams, things can get a little complicated. A simpler method of illustrating valence electrons was developed in the early 20th century.

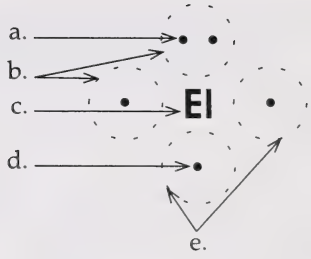
Nelson CHEMISTRY

Gilbert N. Lewis was the first person to develop a simple model that illustrated the rules for valence electrons. To learn about **Lewis' model**, read the section Lewis Models on page 206 of *Nelson Chemistry* and answer the next questions.

Lewis model – a way to represent the way molecules or atoms join together by using dots to represent valence electrons; by pairing dots, bonds are formed until each atom in the molecule gains a complete octet



8. Label the given diagram using these terms (*El* represents any element):



- element symbol
- valence orbitals
- **lone pair**
- **bonding electron**

lone pair – two electrons that occupy the same valence orbital in an atom (They cannot form any bonds as discussed in this course.)

bonding electron – an unpaired electron that occupies a valence orbital and that forms bonds in an atom

Note: • The dotted areas in the diagram illustrate regions of interest. These dotted circles are not part of a regular electron dot diagram.

• The preceding diagram can be described a number of different ways: Lewis model, Lewis diagram, or electron dot diagram.

9. Create a table with the given headings. Have a space available for each of the following elements: calcium, germanium, potassium, sulphur, nitrogen, aluminum, neon, fluorine, and helium. Fill in the missing information.

Element	Number of Valence Electrons	Electron Dot Diagram	Number of Bonding Electrons	Number of Lone Pairs
calcium				
germanium				

Check your answers by turning to the Appendix, Section 1: Activity 2.

You now know how to draw electron dot diagrams, but at this point it would be useful to practise to ensure you can relate the four rules for filling an atom's orbitals to the electron dot diagram.

10. Explain why each of the following electron dot diagrams is incorrect for the element indicated. Redraw each, using the correct electron dot diagram.

a. carbon: C

b. phosphorus: P

c. boron: B

d. sodium: Na

e. potassium: P

f. sulphur: S

11. How does the electron dot diagram for an atom illustrate the rules that determine the way in which electrons fill the orbitals of an atom?

Check your answers by turning to the Appendix, Section 1: Activity 2.

Take a deep breath. You have just caused a series of valence electrons to be transported across membranes inside your body's cells. But what causes these electrons to move? Your body is one large chemical factory constantly causing electron transfers to occur. All of these electron transfers are related in some way to trends on the periodic table.

Nelson CHEMISTRY

To examine how valence electrons can explain periodic trends, read the section Electronegativities found on page 207 of your textbook.

To graphically summarize what you have just read and show the relationship between reactivity and **electronegativity**, study the following diagram.

electronegativity a relative measure of the desire of an atom to attract or gain electrons when bonding

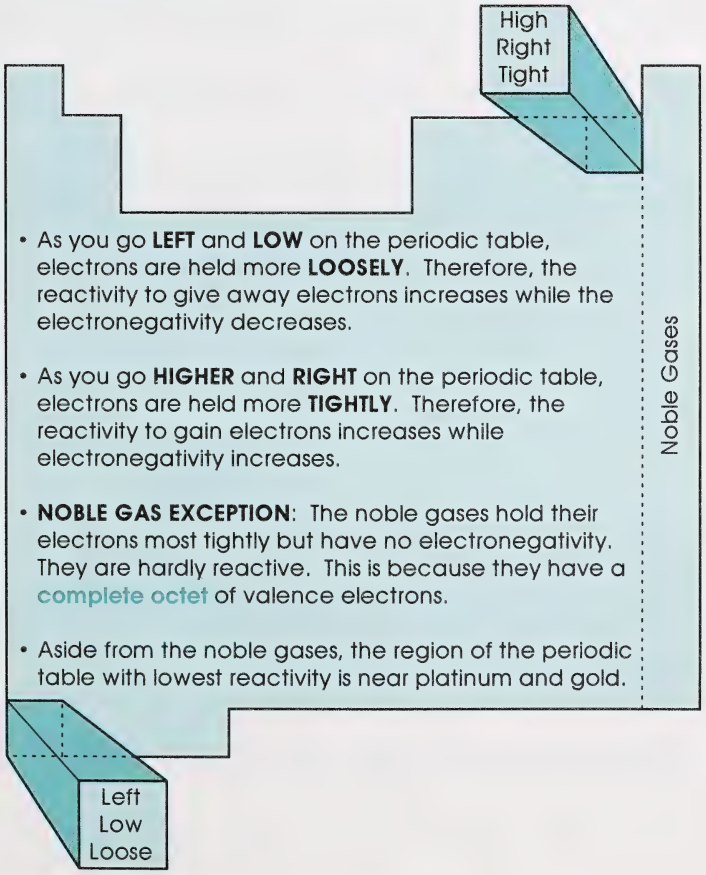
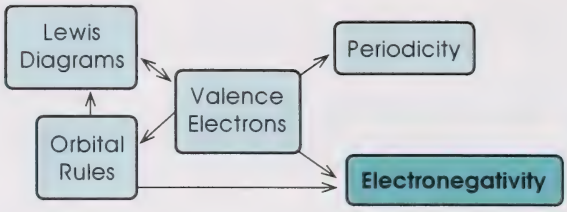

High
Right
Tight
• As you go **LEFT** and **LOW** on the periodic table, electrons are held more **LOOSELY**. Therefore, the reactivity to give away electrons increases while the electronegativity decreases.
• As you go **HIGHER** and **RIGHT** on the periodic table, electrons are held more **TIGHTLY**. Therefore, the reactivity to gain electrons increases while electronegativity increases.
• **NOBLE GAS EXCEPTION**: The noble gases hold their electrons most tightly but have no electronegativity. They are hardly reactive. This is because they have a complete octet of valence electrons.
• Aside from the noble gases, the region of the periodic table with lowest reactivity is near platinum and gold.
Noble Gases
Left
Low
Loose

FIGURE 5.2: Electronegativity and Reactivity Trends

complete octet – having a completely filled valence shell, similar to the noble gases



12. a. The element that is most electronegative is _____.

    b. The element that is least electronegative is _____.

13. Why do the noble gases not have electronegativities?

14. Why do metals generally have low electronegativities while nonmetals generally have high electronegativities?

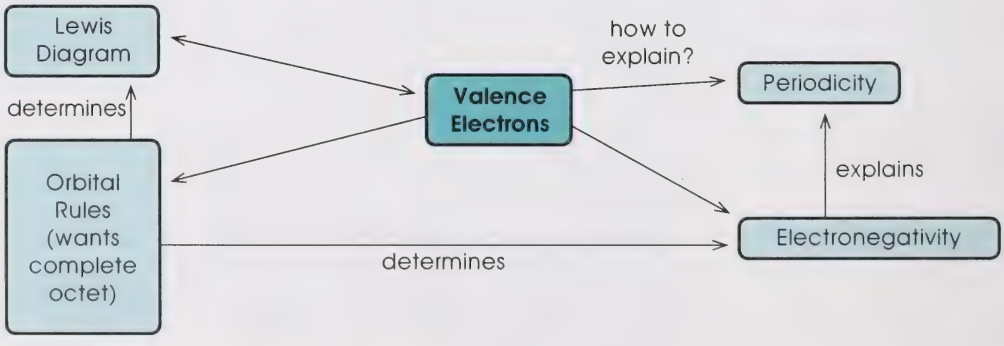
15. Why are elements with low electronegativities and elements with high electronegativities so reactive?

octet rule – when atoms react, they will gain or lose electrons in order to obtain the same number of electrons in their valence shells as a noble gas

16. How is electronegativity related to the **octet rule**?

Check your answers by turning to the Appendix, Section 1: Activity 2.

In this activity, you have examined the role of valence electrons in an atom and how these relate to an atom's location and reactivity on the periodic table.

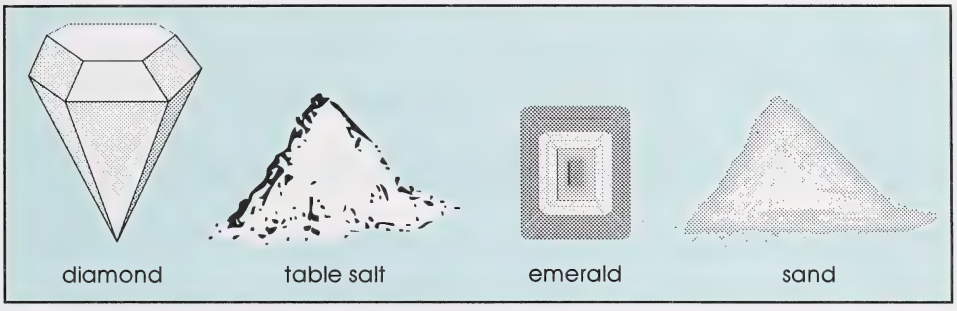


In the next activity, you will examine how electronegativity affects the type of bond one atom will form with another.

ACTIVITY 3

Chemical Bonds

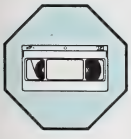
1. Group the four illustrated compounds into two pairs so that each pair contains compounds with similar properties.



At first it may appear that diamond and emerald belong together and table salt and sand belong together. In fact, the correct pairing is diamond and sand as one pair and the table salt and emerald as the other pair.

But why? Aren't diamond and emerald both gemstones? They are, but they are held together by different types of chemical bonds. Table salt and emerald are held together by one type of bond, while diamond and sand are held together by a different type of bond.

In this activity you will learn how bonds form between atoms and examine some of the types of bonds atoms can form.



For an introduction to bonding between atoms, view the video How Atoms Bond (Number 4 in the *Electron Arrangement and Bonding Series*).

Note: The first three videos of the *Electron Arrangement and Bonding Series* are great for reviewing (the theories of an atom, atomic structure, or the definitions of orbitals). These videos include these titles: Introducing the Players, The Rutherford-Bohr Atom, and Electron Arrangement.

Before watching the video How Atoms Bond, preview the following questions.

2. Compare the bonding of helium and hydrogen atoms to other atoms.

3. a. Explain how a bond between two hydrogen atoms can develop. You may use diagrams in your explanation.

b. What is the name given to the type of bond between two hydrogen atoms? How do you describe this type of bond?

4. Why will two helium atoms not bond? Explain.

5. What two factors determine the strength of forces between atoms?

6. a. In the video, the electron arrangement of sodium (Na) is described. Which electrons are identified as the ones key to bonding?

   b. What two reasons are given for sodium's outer electron being loosely held?

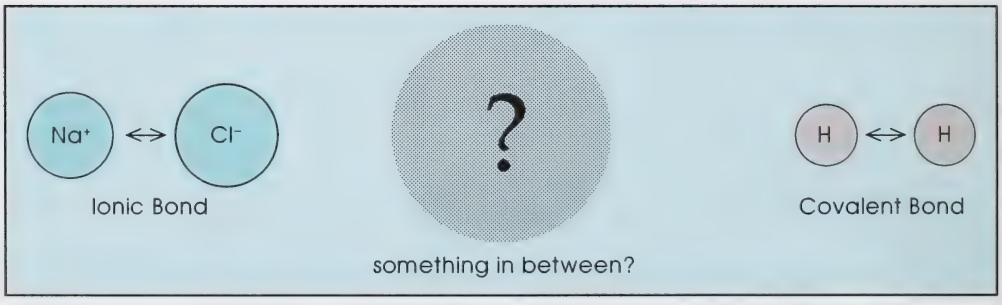
7. a. Describe the process that leads to a bond forming between a sodium atom and a chlorine atom.

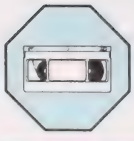
   b. What name is given to the Na-Cl bond?

8. List the three possible bond types given and provide a description of each.

Check your answers by turning to the Appendix, Section 1: Activity 3.

The video leaves the impression that bonding is not only a matter of extremes – there may not be only covalent bonds between like atoms and ionic bonds between vastly different atoms.





What is in between? To discover more about the bonding continuum, view the fifth video in the *Electron Arrangement and Bonding Series* entitled Molecular Substances and Covalent Crystals. Preview the following questions before watching the video.

9. Why do the noble gases exist in a generally unreactive state?

10. a. What happens to the valence shell or outer energy level of an atom when it forms a bond?

    b. Why is this arrangement stable?

valence shell – a synonym for the four valence or outer orbitals of an element

11. When atoms achieve an octet of electrons, to what do their electron arrangements become similar?

12. Define the following terms:

    a. non-polar covalent bond b. ionic bond c. polar covalent bond

13. Draw a continuum that would indicate how non-polar covalent, polar covalent, and ionic bonds are related to each other.

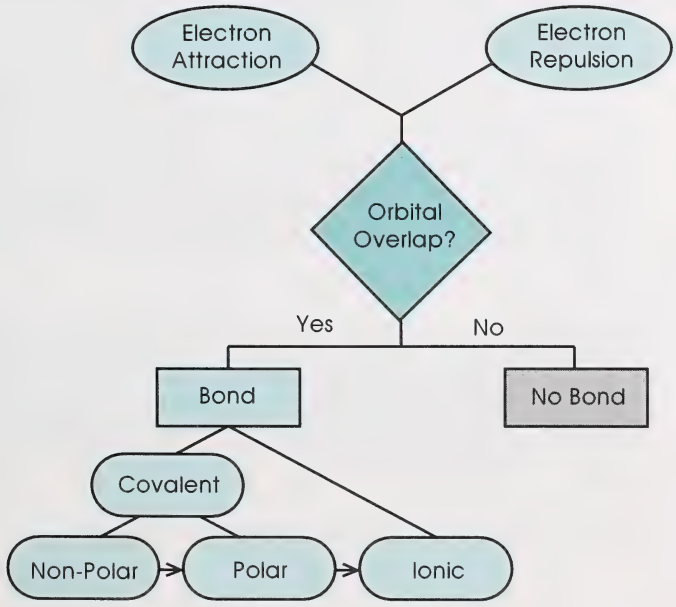
14. Complete a table similar to the following that compares and contrasts single covalent, double covalent, and triple covalent bonds.

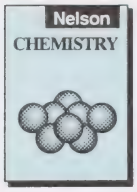
Type of Covalent Bond	Similarities	Differences
single		

Check your answers by turning to the Appendix, Section 1: Activity 3.

In the preceding two videos, you learned that bonds are formed due to the attraction of one atom's electrons by another atom's nucleus. If the attractive forces are such that when the attractive and repulsive forces balance there is orbital overlap, a bond is formed. The type of bond formed depends on the electronegativity differences between the atoms. The greater the difference the more ionic character the bond has.

orbital – a region of space around an atom where an electron will most likely be found





How does this information relate to the octet rule? Read the section Chemical Bonding on pages 207-208 of your textbook to help you answer the following questions.

15. What is the role of the octet rule in chemical bonding?

16. What is the role of electronegativity in chemical bonding?

Check your answers by turning to the Appendix, Section 1: Activity 3.

You have learned that all chemical bonds are formed by the attraction of one atom's electrons by another atom's nucleus. You also have noticed that the differences in electronegativities of atoms will determine the type of bond that forms. If a non-polar covalent or polar covalent bond forms between atoms, the resulting substance is molecular. If an ionic bond forms between atoms, the resulting substance is ionic.

Carefully examine Figure 5.3 and Figure 5.4.

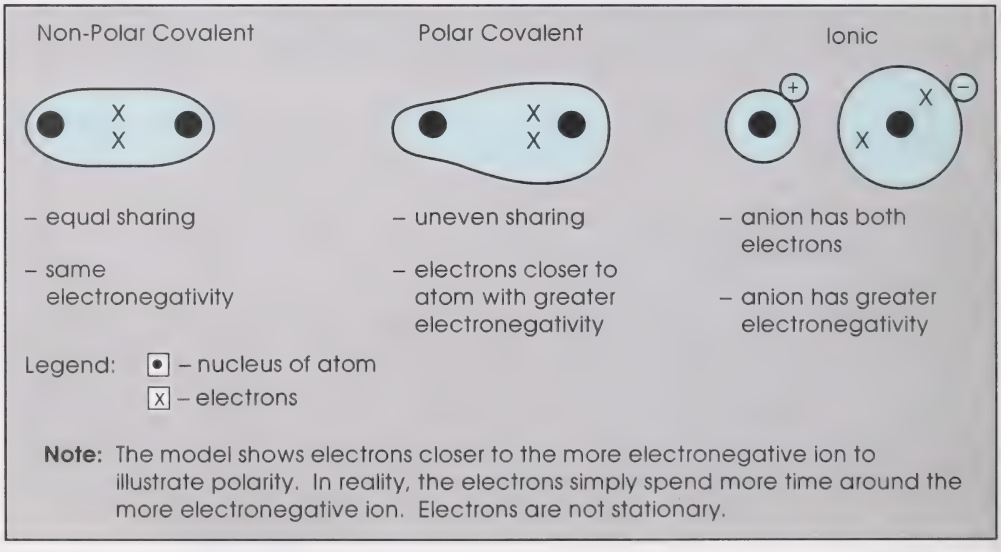

Non-Polar Covalent
Polar Covalent
Ionic
X
X
X
X
X
X
+
−
– equal sharing
– same electronegativity
– uneven sharing
– electrons closer to atom with greater electronegativity
– anion has both electrons
– anion has greater electronegativity
Legend: ⊡ – nucleus of atom
⊠ – electrons
Note: The model shows electrons closer to the more electronegative ion to illustrate polarity. In reality, the electrons simply spend more time around the more electronegative ion. Electrons are not stationary.

FIGURE 5.3: Comparison of Bond Types

Difference in Atoms' Electronegativities	0	0.9	1.4	1.7	1.9	2.5	3.0
% Ionic Character	0	20	40	50	60	80	90
% Covalent Character	100	80	60	50	40	20	10

FIGURE 5.4: Comparison of Electronegativity to Bond Type

17. When a bond is formed between two atoms, around which atom do the electrons spend more time?

18. Explain why chemicals such as $CaCO_3$, $CuSO_4$, and KNO_3 are ionic compounds.

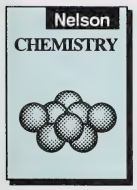
19. Create a chart with three columns. Label the first column **Atoms Bonding**; the second **Type of Bond Formed**; and the third **Description of Bonding Electrons**. Enter the following combinations in the **Atoms Bonding** column. Fill in the missing information.

- S and Mg
- C and S
- F and F
- N and Cl
- H and O
- Fe and O
- P and F

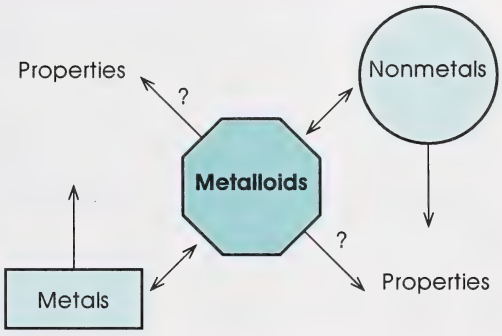
Check your answers by turning to the Appendix, Section 1: Activity 3.

metalloids – the set of elements from Groups 13 to 17 having both metallic and nonmetallic properties

You may have noticed that no mention has been made of the **metalloids**. The metalloids of the periodic table have special properties.

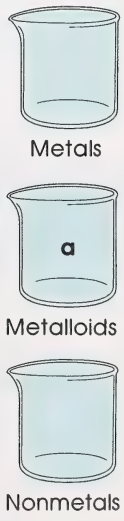


Read the section Metalloids found on pages 208-209 of *Nelson Chemistry* to find out more about these unique elements.



20. Several properties of metals, metalloids, and nonmetals are given here. Draw and label three beakers. Fill the beakers with the correct properties by placing the letters of the various qualities into each beaker. The letters may be used more than once. One example is done for you.

a. very hard
b. solid does not conduct heat/electricity
c. brittle
d. semiconductor
e. soft
f. malleable
g. liquid
h. solid does conduct heat/electricity
i. high melting point
j. ductile
k. shiny
l. solid
m. gas
n. form cations
o. dull appearance



21. a. What type of bonds do metalloids form?

    b. How does their bond type explain metalloids' special properties?

Check your answers by turning to the Appendix, Section 1: Activity 3.

So far you have learned the basics of bonding. In what ways are the substances that have been discussed used? How do ionic and molecular compounds influence your daily life?

22. In order to become more aware of the role ionic and molecular compounds play in your life, complete the following table. The first compound, water, is done for you.

Substance	Type of Bond (non-polar covalent/polar convalent/ionic)	Molecular or Ionic?	Use or Description
water	polar covalent	molecular	– for drinking – 80% of your body's mass
	ionic		– found in saline solution – seasons food
coal			– burned to produce electricity in many places
rust			
			– fuel burned in most automobile engines
nitrogen dioxide			– reddish-coloured smog
bleach			– cleaning agent that conducts electricity
			– main constituent of air
sugar			
DNA			
			– primary ingredient of computer chips
baking powder			

Check your answers by turning to the Appendix, Section 1: Activity 3.

Chemical bonds are present everywhere around you. In this section, you learned how and why these bonds form, as well as the role that electronegativity plays in determining the type of bond that will form.

In the next section, you will examine ionic bonding more closely to learn why compounds such as salt and emeralds have their particular properties.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

To understand bonds, remember the following:

- You need two electrons, one from each atom, to make a chemical bond.
- All bonds are the result of the attraction of opposite charges. If a negative electron on one atom attracts the positive nucleus of another atom, and vice versa, a bond can form.
- The type of bond formed is determined by an atom's electronegativity which shows an atom's attraction for the bonding electrons.

1. To review the relationship between electronegativity and bond types, complete the following chart with these terms:

   - metal with nonmetal
   - nonmetal with nonmetal
   - non-polar covalent
   - molecular
   - $CaCl_2$
   - H_2O
   - ionic
   - CH_4

Bond Type	Electronegativity Difference	Type of Compound Formed	Elements Involved	Example
	zero	nonmetal with nonmetal	molecular	
polar covalent	small to medium			
	large		ionic	

Note: Metalloids usually combine with other elements to form **covalent** bonds.

The octet rule states that every atom wants eight electrons in its valence shell. Electronegativity plays a major role in determining whether an atom will gain or lose electrons to achieve the octet.

The following chart shows how the number of valence electrons determines an atom's reactivity and electronegativity.

Number of Valence Electrons	Reactivity Trend		Electronegativity Trends	
	Degree	Reason	Degree	Reason
1	very reactive	It is easy to lose an electron and become stable like a noble gas with a complete octet.	low	It is easier to lose one electron than gain seven electrons to achieve an octet.
4	low reactivity	It has a half-filled octet and doesn't gain or lose electrons.	medium	It is halfway to completing its octet (valence shell). It completes the octet by sharing rather than gaining or losing electrons.
7	very reactive	It only needs one more electron to complete its octet.	very high	It needs only one more electron to complete its octet.
8 (noble gas)	not reactive	It has a complete octet.	none	It has a complete octet.

FIGURE 5.5: Reactivity and Electronegativity Trends Based on Valence Electrons

Use Figure 5.5 to answer the following questions.

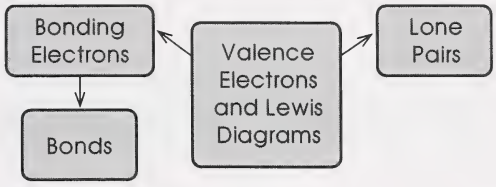
2. a. Create a chart using the following format. Fill in the required information.

Element	cesium	aluminum	chlorine	silicon	argon
Degree of Reactivity					
Reason for Degree of Reactivity					
Electronegativity					
Reason for Size of Electronegativity Value					

b. Describe the relationship between degree of reactivity, electronegativity, and position on the periodic table of elements.

3. Why does an atom with two valence electrons, such as magnesium, have a high reactivity and low electronegativity?

The number of valence electrons also determines the number of bonds an atom will make. Lewis electron dot diagrams make this easier to see.



4. Fill in the following blanks with the symbol of the element that corresponds to the given Lewis electron dot diagrams. The possible elements are francium, nitrogen, krypton, and carbon.

a.

c.

b.

d.

Check your answers by turning to the Appendix, Section 1: Extra Help.

Enrichment

Do **one** of the following activities.

1. Two elements that have been proposed as possible semiconductors for use in transistors and other solid state products are germanium and silicon.

   Do a historical study on the development of the computer chip from the germanium transistor to the present. Include a discussion of the type of bonding these elements display as well as how this affects their physical properties. Also include a discussion of how bonding plays a role in the development of new computer chips.

2. Metals used for joints, plates, bone screws, and other replacements for human body parts are often made of alloys containing cobalt, chromium, titanium, and stainless steel. What properties of these metals make them so suitable for use in the human body? Relate this to what you have learned so far about bonding.

3. If you have access to the book *One Minute Readings: Issues in Science, Technology, and Society* (Richard F. Brinkerhoff, 1992, Addison-Wesley), read Issue 32: Manganese, Platinum, Chromium, and Foreign Policy on page 56.

   How should this issue affect Canada's foreign policy toward South Africa? Do research in the library or interview a government official involved in policy-making to help you make a well-informed decision and present a solid argument.

Check your answers by turning to the Appendix, Section 1: Enrichment.

Conclusion

Imagine driving across Canada from Vancouver to Halifax. What happens to the scenery? From the West Coast beaches you travel eastward and enter the mountains. A little further and you get to Alberta and the flat prairies. Continuing east you enter the Canadian Shield with its many rocks and rolling hills. You then travel through small rolling mountains before arriving in Halifax and an ocean again. Notice how the pattern across Canada is similar to that of periodicity: hilly-flat-hilly compared to high reactivity-low reactivity-high reactivity.

In this section, you examined reasons for this periodicity as you developed an activity series of your own. Lewis electron dot diagrams helped you visualize the role of the valence electrons in determining periodicity and electronegativity trends. Finally, you were able to relate this information to the types of chemical bonds that atoms form and see how these bonds are significant in your daily life.

In the next section, you will examine ionic bonding more closely to learn why compounds such as salt and emeralds have their particular properties.

30

Section 1 Assignment: The Basics of Bonds

Review the Evaluation information found in the introductory pages of this module.

It is important to number and clearly identify each page with the following information at the top:

Chemistry 20 – Module 5 Section 1 Assignment Page # Name and ID #

Be sure to write legibly. Leave a wide left margin and number all of your pages.

Science Skills
- ☐ A. Initiating
- ☐ B. Collecting
- ☐ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☑ F. Evaluating

1. A student was trying to determine the activity series for six metals by reacting them with dilute hydrochloric acid (as was done in Activity 1). The six metals the student used were cadmium, cesium, gold, manganese, strontium, and tin.

   a. Use the information on your periodic table for predicting what the activity series should be for these six metals from most reactive to least reactive. Include a reason for your prediction. **(2 marks)**

   Response Page Setup

   You may organize your response in the form of a table as follows.

Order	Metal	Reason
1		

   In terms of order, number 1 would be the most reactive.

   b. The student obtained the following results from the investigation. What is the activity series for the metals based on these observations (from most reactive to least reactive)? **(1 mark)**

Metals Reacted with Dilute $HCl_{(aq)}$

Metal	Observations
cadmium	There was no reaction after 1.0 h.
potassium	The potassium reacted vigorously, causing the beaker to explode.
gold	Some bubbles were seen attached to the metal after 1.0 h.
manganese	A steady bubbling of the metal occurred.
calcium	Very vigorous bubbling was observed.
tin	The metal became slightly discoloured after 45 min. A few bubbles were also noticed.

   c. Give two reasons for the possible discrepancy in the results. **(2 marks)**

Response Page Setup

Reproduce the science skills assessment box after your response to this question. Remember to indicate your evaluation of your skill level for each identified science skill. Be sure to include the spaces for teacher assessment.

Self:	A.	☐	B.	☐	C.	☐	D.	☐	E.	☐	F.	☐
Teacher:	A.	☐	B.	☐	C.	☐	D.	☐	E.	☐	F.	☐

2. Draw Lewis electron dot diagrams for the following elements: **(3 marks)**

   a. xenon b. silicon c. selenium

3. Match the following terms with the given definitions.

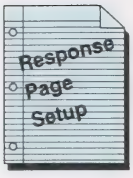
• ionic bond	• non-polar covalent bond
• polar covalent bond	• bonding electrons
• valence electrons	• lone pair
• electronegativity	• activity series

a. the electrons contained in the highest energy level of an atom **(1 mark)**

b. when one electron from each atom is shared between two atoms **(1 mark)**

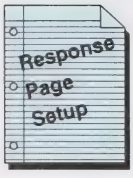
c. when one atom loses one or more electrons to another atom **(1 mark)**

d. a relative measure of the degree to which an atom attracts bonding electrons **(1 mark)**



Organize your response by writing the proper term beside the letter of the correct definition.

4. Describe the type of bond that will form between the atoms when each element of the second period in the periodic table (Li, Be, B, C, N, O, F, and Ne) reacts with chlorine. Give reasons for your answers. **(4 marks)**



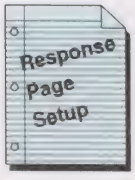
Organize your response in the following manner.

Atom Combination	Type of Bond	Reason

5. Explain why one person may predict germanium to form an ionic bond with chlorine, while another may predict germanium to form a polar covalent bond with chlorine. **(2 marks)**

6. In one-half to three-quarters page, explain how the octet rule and electronegativity can be used to describe the bonding continuum that exists from an equal sharing of electrons to a complete electron transfer. **(6 marks)**

7. Give an example (other than water) of one substance containing non-polar covalent bonds, one substance containing polar covalent bonds, and one substance containing ionic bonds. For each example describe two uses or functions of the substance in your daily life. **(6 marks)**



Organize your response in the form of a table.

Bond Type	Substance	Functions

SECTION 2

Ionic Bonding

WESTFILE INC.

Have you ever eaten a whole meal in which no salt had been added to anything? Or can you think back to a time when your meal was too salty? What about the people that are on salt-restricted diets? Salt plays an important role in your daily life. You need it for such basic things as allowing the words from this page to be transferred by nerve impulses to your brain. Without it you would not be alive. But too much of it can also be a major health risk.

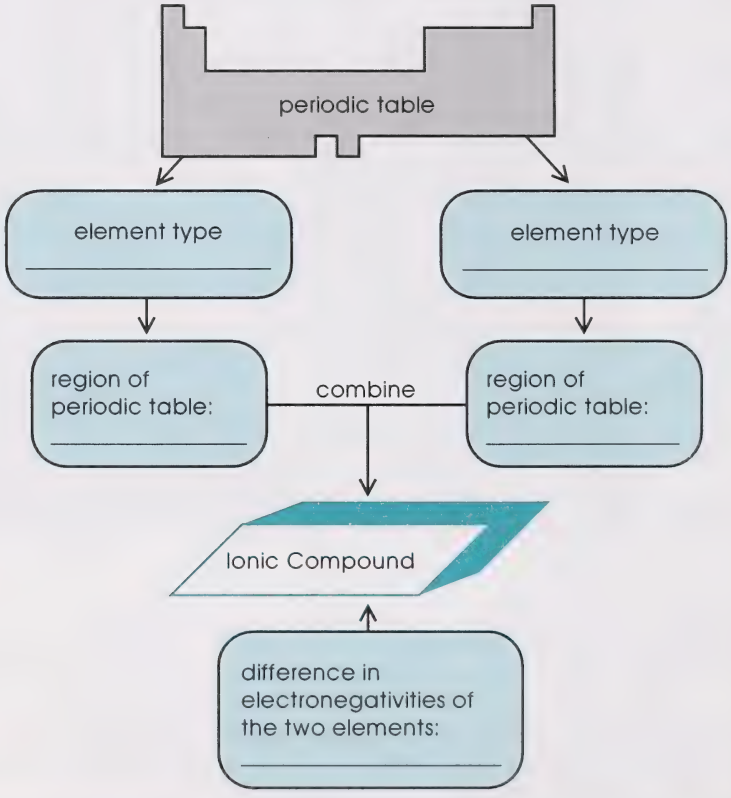
Salt is not the only ionic substance that you use in your daily life. There are many others. In this section you will examine ionic substances. You will learn how to predict the chemical formulas of ionic solids using basic bonding principles and explain why ionic compounds form. You will then explore some of the ways ionic bonding affects your daily life. In addition, you should also be able to explain why different ionic substances have different shapes.

ACTIVITY 1

What Does Being Ionic Mean?

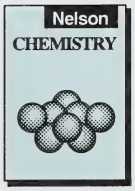
Can you think of a substance that contains an ionic bond? Perhaps your first thought would be of the ionic compound table salt (sodium chloride, NaCl). There are many other possible compounds, though, all made from elements on the periodic table.

1. Complete the following diagram to show the factors determining where the components of ionic compounds come from and how electronegativity is involved in ionic compound formation.



Check your answers by turning to the Appendix, Section 2: Activity 1.

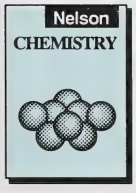
Ionic compounds are easily identified by checking the positions of their component elements on the periodic table. Do you recall how the ionic compound names and formulas are derived?



In Science 10 you learned to write the formulas and names of ionic compounds. To review this procedure, read Section 3.3: Chemical Names and Formulas on pages 80-84 in your textbook (Omit page 81). This review will also help you in later activities.

Remember these important ideas as you read.

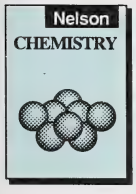
- Always apply the **zero sum rule**: The total + and – charges in an ionic formula must add up to zero. This is why you multiply each ion by a coefficient.
- Metals (positive ions) are named first; nonmetals (negative ions) are last.
- Except for transition metals, cations (positive ions) retain their element names.
- Monatomic anions (negative ions) end in *ide*.
- When naming transition metals with multiple charges, include a roman numeral after the positive ion name to indicate the size of the charge.
- Polyatomic ions behave as one single species.



2. Do question 1 (a-j) from page 85 of your textbook to reinforce what you have read.

Check your answers by turning to the Appendix, Section 2: Activity 1.

Did you know that ionic compounds are found everywhere around you? In Module 1, you saw examples of soluble ionic compounds in solutions. Can you name any examples of ionic solids in your everyday life?



Read section 8.2: Ionic Compounds on page 209 to the middle of page 210 in *Nelson Chemistry* to see some examples of where ionic compounds are found in your surroundings.

3. Do question 23 from page 212 of your textbook to expand on the list of ionic compounds you read about. Include at least ten compounds in your list and record the data in a table that has the following headings. An example is done for you.

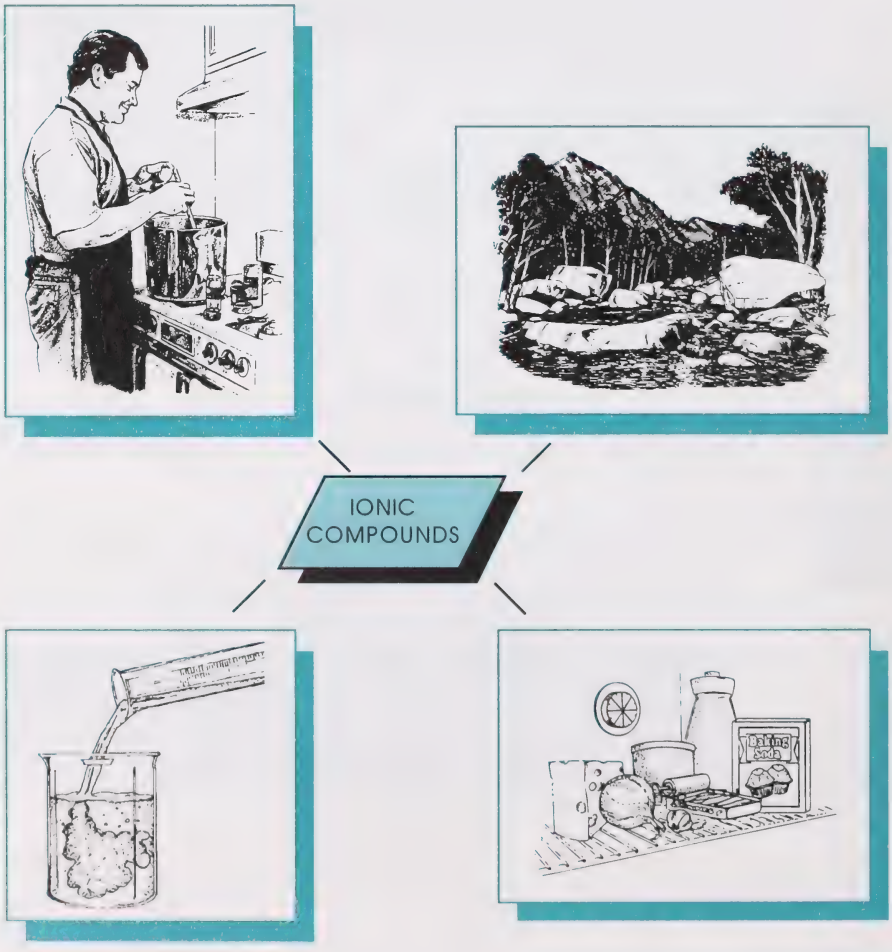
Product Name	Ionic Compound Name	Chemical Formula	Use
table salt	sodium chloride	NaCl	a food seasoning

4. Reproduce the following list and circle the items in which you could find ionic compounds.

- lakes
- potato chips
- ocean
- paint
- plastic
- rocks
- cleaning supplies
- protective metal surfaces
- fertilizers
- you
- soft drinks
- canned foods
- fresh vegetables
- some medications

Check your answers by turning to the Appendix, Section 2: Activity 1.

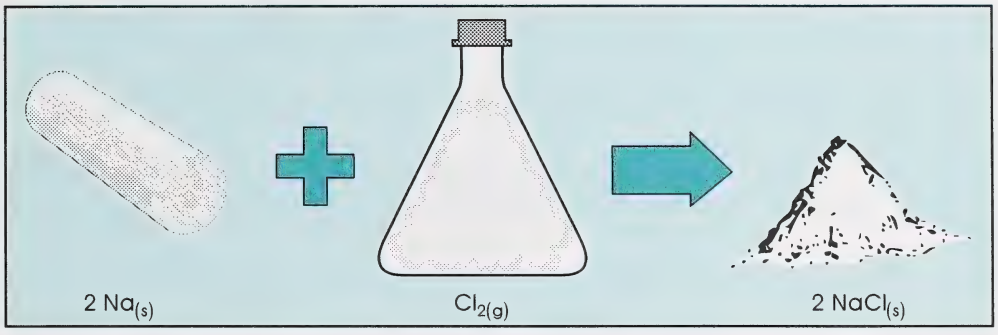
Ionic compounds are used for everything from food additives to fertilizers to cleaning materials to the walls of your house. They are also found in such things as minerals, your body, and even the fluoride of your toothpaste.



You use the periodic table to name them or write their formulas, but how and why do ionic compounds form? These questions will be answered in Activity 2.

ACTIVITY

2 Ionic Compound Formation



Nelson CHEMISTRY

You know how to name ionic compounds, but have you ever wondered how or why ionic compounds form in the first place? For an explanation of how ionic bonds form, read the first three paragraphs of the section on formation of ionic compounds starting on page 210 of *Nelson Chemistry*. Then answer the next three questions.

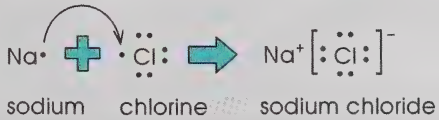
1. a. What is the collision-reaction theory?

   b. How does the collision-reaction theory explain the formation of ionic bonds?

2. What causes electrons to transfer from metals to nonmetals?

The formation of ionic compounds can be illustrated using Lewis electron dot diagrams.

Example



3. Using electron dot diagrams illustrate how the following ionic compounds are formed:

   a. KCl

   b. LiBr

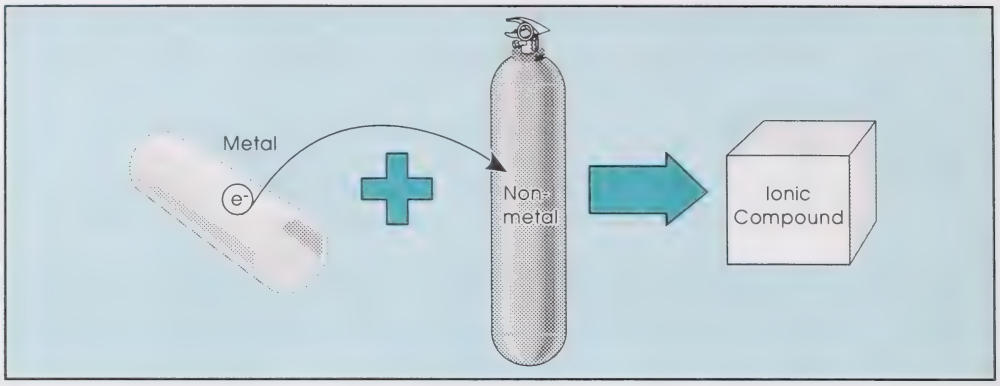
   c. CaO

   d. FeS (Hint: Since iron forms Fe^{2+}, draw iron with only two valence electrons.)

   e. Ag_2S

   f. $MgBr_2$

   g. $NiCl_3$



In the preceding question, you used electron dot diagrams to illustrate how ionic compounds are formed. The diagrams clearly show the electron transfer that happens when the ions form. However, this method becomes cumbersome when you try to use it to demonstrate how a more complex ionic compound like aluminium oxide (Al_2O_3) forms. In addition, no real consideration is given to the fact that gases such as fluorine, oxygen, and nitrogen are **diatomic**.

diatomic – having two atoms in each molecule

Finish reading the section Formation of Ionic Compounds on page 211 of your textbook to learn another method, oxidation-reduction reactions, that shows electron transfer. Notice that **oxidation** and **reduction** always occur together. The following diagram shows why.

oxidation – loss of electrons

reduction – gain of electrons

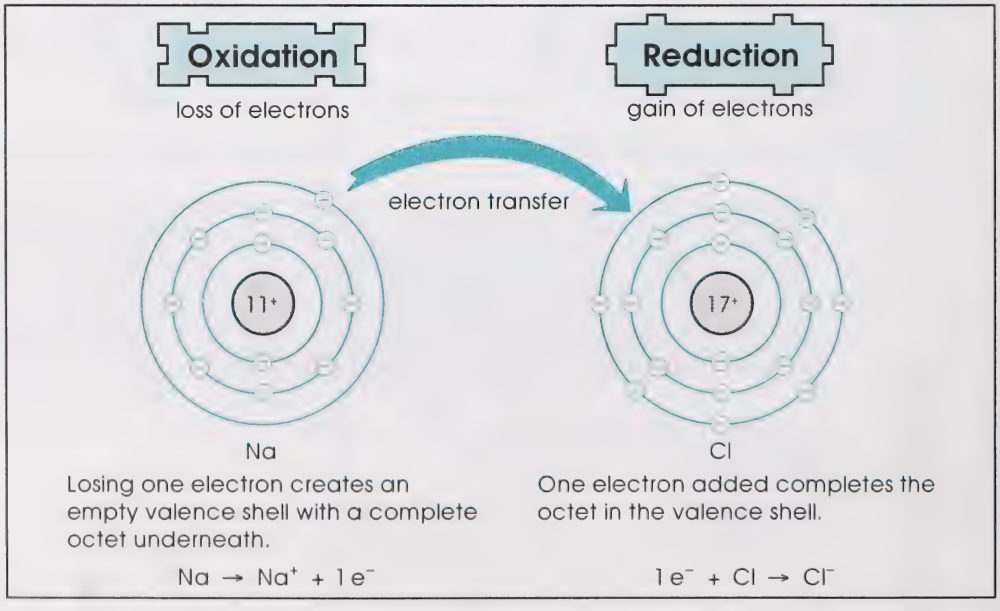


FIGURE 5.6: Oxidation and Reduction

Answer the following questions to help you become more familiar with the terms oxidation and reduction and to see how they are related to the ionic formula of a substance.

4. Fill in the blanks.

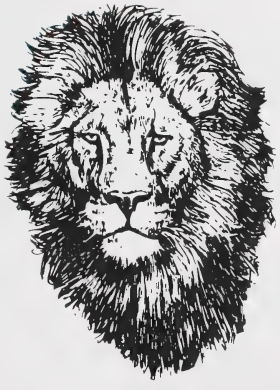
   a. When an atom loses electrons to become a cation, _____ has occurred. When an atom gains electrons to become an anion, _____ has occurred.

   b. Usually, _____ are oxidized and _____ are reduced.

5. Why must the total sum of the ion charges in an ionic compound always equal zero?

Check your answers by turning to the Appendix, Section 2: Activity 2.

Two ways to remember the oxidation and reduction definitions are as follows:



LEO says **GER**
Loss of **E**lectrons is **O**xidation
Gain of **E**lectrons is **R**eduction

OR

OIL RIG
Oxidation **I**s **L**oss of electrons
Reduction **I**s **G**ain of electrons

law of conservation of matter – scientific law that states matter can neither be created nor destroyed

Notice, again, that whenever oxidation occurs, reduction has to occur. This is because of the law of conservation of matter – electrons can neither be created nor destroyed. Electrons are only lost by one atom when there is another atom or atoms present to gain the electrons.

6. Why is the number of electrons lost in a oxidation-reduction reaction always equal to the number of electrons gained?

half-reaction – an equation representing half of an overall process – either oxidation or reduction

As Figure 5.6 Oxidation and Reduction showed earlier, the loss and gain of electrons can be illustrated for atoms in half-reactions. Practise writing these reactions by completing the following questions.

7. For each of the following elements, identify whether the element would undergo oxidation or reduction. Then write the half-reaction for the element. An example is done for you.

> Example
>
> potassium: Potassium would undergo oxidation.
>
> The half-reaction is as follows: $K \rightarrow K^+ + 1e^-$
>
> **Note:** The half-reaction is written without states to simplify your learning at this point. Usually, the reactions would occur in aqueous conditions and the ions would have $_{(aq)}$ states.

a. strontium

b. chlorine

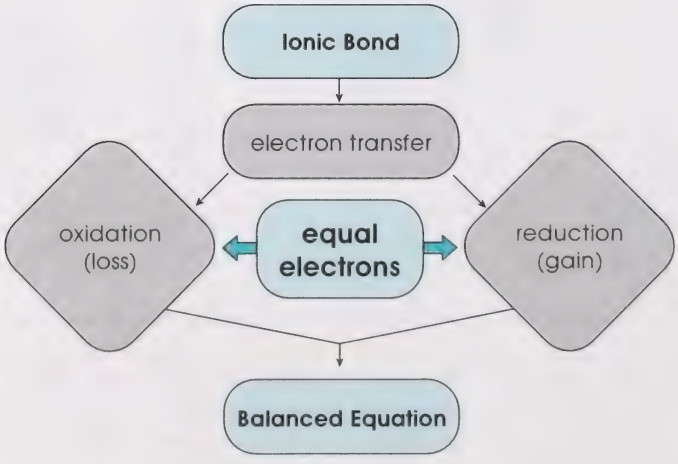
c. sulphur

d. zinc

e. oxygen

f. nitrogen

Check your answers by turning to the Appendix, Section 2: Activity 2.



Since you can identify half-reactions in an oxidation-reduction reaction, you should be able to put these half-reactions together to get an overall balanced chemical equation. The important thing to remember is that the number of electrons transferred must be equal, that is, loss must equal gain.

8. The following table illustrates the writing of net ionic reactions.

Reacting elements	magnesium and chlorine
Oxidation half-reaction	$Mg \rightarrow Mg^{2+} + 2\,e^-$
Reduction half-reaction	$Cl_2 + 2\,e^- \rightarrow 2\,Cl^-$
Balanced net reaction	$Cl_2 + Mg \rightarrow MgCl_2$
Number of electrons lost (2) =	Number of electrons gained (2)

Prepare similar tables for the following pairs of reacting elements:

a. beryllium and fluorine

b. cadmium and nitrogen

c. iron and oxygen (product is iron(III) oxide)

Check your answers by turning to the Appendix, Section 2: Activity 2.

Answer the following question without the assistance of a chart showing you the steps to follow.

9. Write the oxidation-reduction reactions by the half-reaction method for the following. Use the most common ions for metals where applicable.

a. $K + I_2 \rightarrow$

b. $Ba + N_2 \rightarrow$

c. $S + Ni \rightarrow$

d. $Sn + N_2 \rightarrow$

Check your answers by turning to the Appendix, Section 2: Activity 2.

You know that an oxidation-reduction reaction involves a transfer of electrons where the electrons lost must equal the electrons gained. But this still does not answer a question such as the following: Which corrodes more easily, steel or brass?

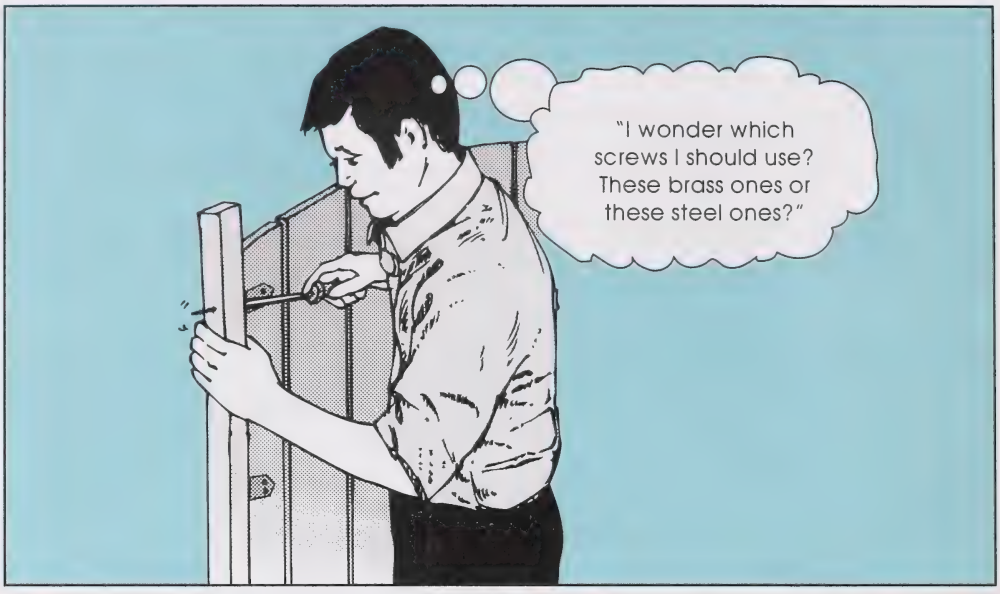


FIGURE 5.7: Corrosion and Metals

To answer this question, you must learn about the nature of corrosion. Corrosion is an oxidation-reduction process in which metals are oxidized by oxygen in the presence of moisture (water). The most common example is the formation of rust from iron.

Corrosion such as this causes billions of dollars of damage each year. All you have to do is look at some cars to realize this!

The following diagram shows some of the various ways in which corrosion may be prevented or slowed.

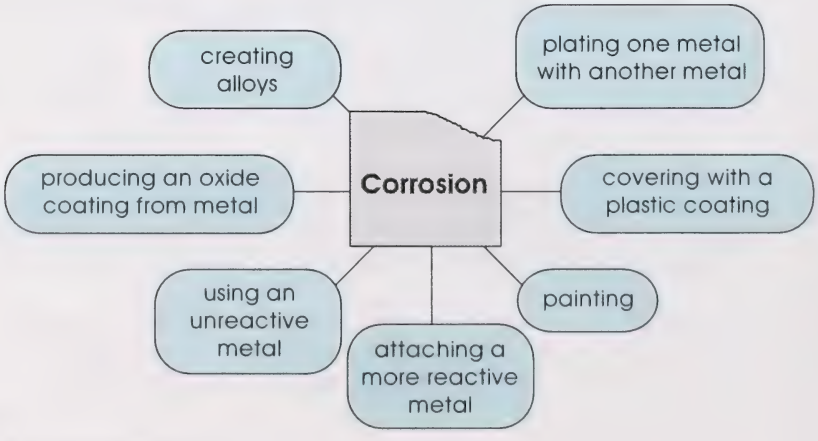


FIGURE 5.8: Corrosion Prevention

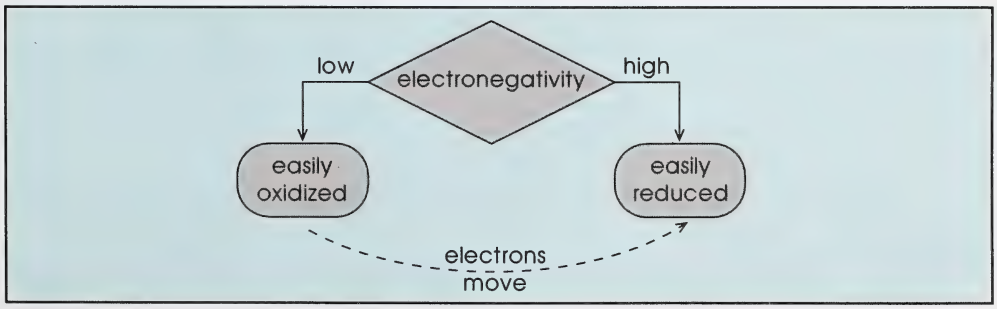
10. Using the methods of corrosion prevention in Figure 5.8, complete the following table in order to see examples of some of the methods of corrosion protection used.

Method	Example
	• chrome plating • galvanized metal • lining on tin cans
attaching a more reactive metal to protect another	• used in salt water to protect motors and ship hulls • protects some metal parts in pipelines
	• aluminum oxide on aluminum • zinc oxide on zinc
	• stainless steel

Check your answers by turning to the Appendix, Section 2: Activity 2.

In the first activity of this module, you learned that some metals react with acids more easily than others. Why? The reason is because some metals are more easily oxidized than others. You also learned in the first section that electronegativity was related to the reactivity of the elements. From this, you derived the very general rule that the lower the electronegativity of an element, the easier it reacts.

For metals that are oxidized, the preceding general statement can be reworded to say that the lower the electronegativity of a metal, the more easily it is oxidized.



People make use of this fact for helping prevent corrosion and for making general predictions about which metals will corrode and why.

Answer the following questions to investigate how using different metals can prevent corrosion in your everyday life.

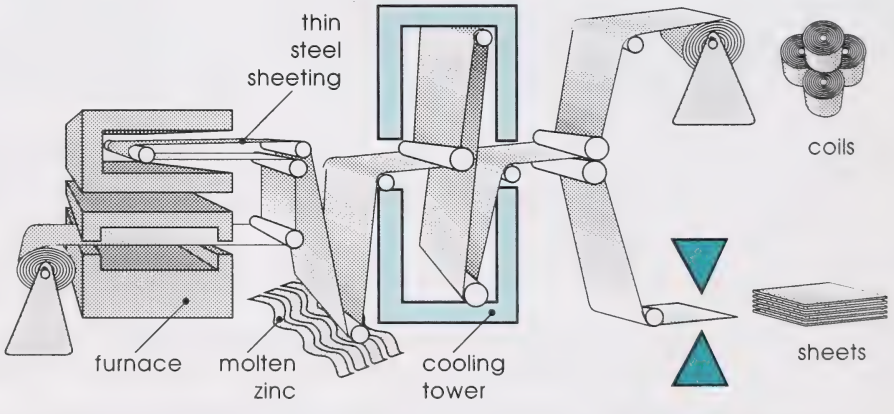
11. Knowing that brass is mostly copper and steel is mostly iron, which screws should the person in Figure 5.7 use? Why?

12. Gold and platinum are two *precious* metals. In terms of chemical reactivities, why are they *precious*?

Check your answers by turning to the Appendix, Section 2: Activity 2.

Did you notice that the preceding method of corrosion prevention could get expensive? Rather than using fairly unreactive metals, some methods used to combat corrosion use oxidation-reduction reactions selectively. An example is found in the process of galvanization. Galvanized metal is steel that has been coated with a thin layer of zinc. The zinc reacts before the steel does because it is more easily oxidized. The result is that the metal forms a thin zinc oxide coating that protects the metals from further corrosion.

galvanization – the coating of metals to prevent corrosion



The steel enters a furnace where it is heated. The steel is then slowly cooled to prepare it for galvanization. It is then passed through molten zinc and cooled further to harden the surface.

FIGURE 5.9: The Galvanization Process

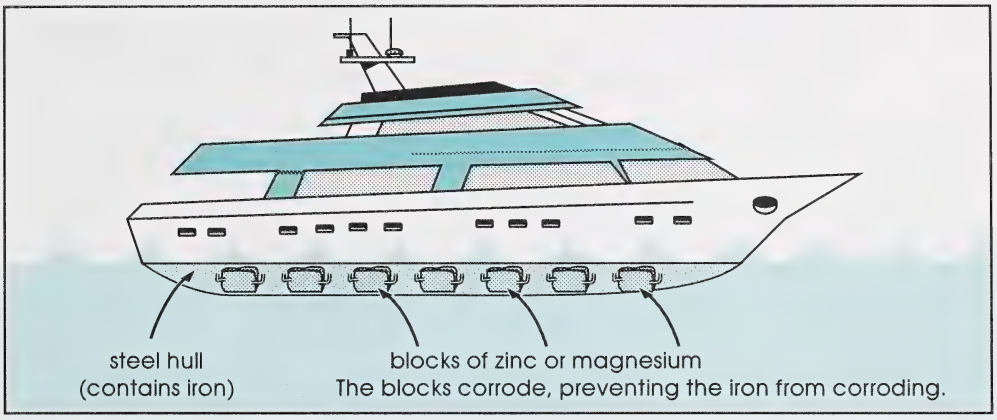
13. What would happen if zinc did not form a nonreactive zinc oxide coating over the galvanized metal?

cathodic protection – attaching a more reactive metal to a less reactive one to protect the less reactive metal from corrosion

Cathodic protection works in a similar manner to galvanization except that the more easily oxidized metal is separate from, but still attached to the metal you want protected. A conducting wire connects the two metals. Surrounding moisture that allows for conductivity is also necessary. The more easily oxidized metal passes electrons along the wire to the protected metal, thus preventing the protected metal from losing electrons.

Nelson CHEMISTRY

An example of this process is shown in Figure 13.21 on page 404 of your textbook. Electrons flow from the piece of magnesium through a wire to the gas tank, as the magnesium slowly oxidizes in the ground. The metal in the gas tank is therefore prevented from corroding because electrons are flowing toward the tank. This method is also used in ships and boats for protecting the steel hulls and engines from corrosion.



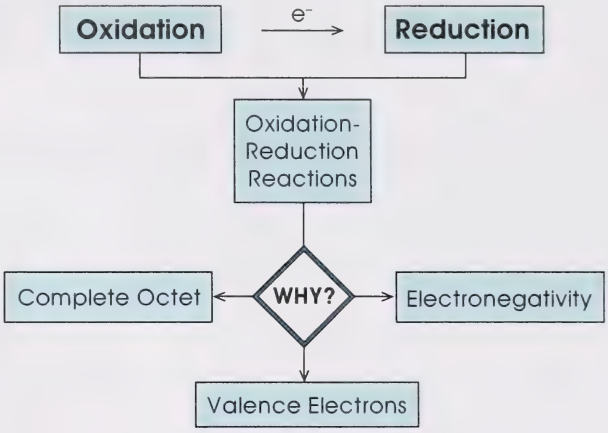
14. Suppose that you want to cathodically protect the following metals: beryllium, chromium, and copper. The metals that you want to oxidize for protecting the others are cadmium, platinum, manganese, and magnesium. Reproduce the following diagram. Connect each metal needing protection to a metal that will oxidize more easily than itself.

Metals to Protect	**Oxidizing Metals**
Be	Cd
Cr	Pt
Cu	Mn
	Mg

Check your answers by turning to the Appendix, Section 2: Activity 2.

Oxidation-reduction reactions occur all around you. One of the most common examples is corrosion. Many methods are used for preventing corrosion, some of which involve other oxidation-reduction reactions. Regardless, oxidation-reduction reactions always involve a transfer of electrons from the element being oxidized to the element being reduced. Whenever a metal is the element that undergoes oxidation, an ionic compound is formed.

You are now able to explain how and why the reaction occurs. This can be supported by electron dot diagrams and writing the oxidation-reduction reaction using half-reactions.

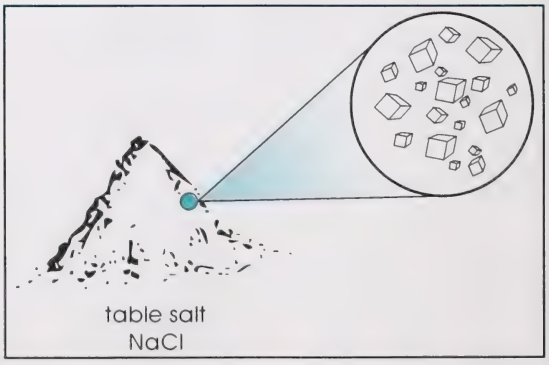


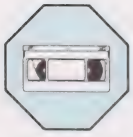
ACTIVITY 3

Ionic Models

Look at a few crystals of salt. If you have a magnifying glass, examine the crystals under the magnifying glass. What do you see? Why do all the salt crystals have basically the same shape?

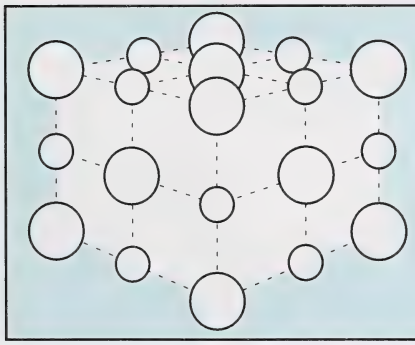
This activity will explore the reasons why ionic solids have the shapes they do. You will also build your own model of a salt crystal.





As an introduction to this activity, view the video Metals and Ionic Solids, Number 6 from the *Electron Arrangement and Bonding Series* . Pay particular attention to the introduction and the information on ionic solids. Preview the following questions before watching the video.

1. Describe how covalent and ionic bonds are formed.
2. What is the relationship between bond types and the properties of a substance?
3. Does the formula for table salt, NaCl, imply that only one ion of each charge is involved in a crystal? Explain.
4. In the following crystal diagram, write + and – charges on the ions (circles) to show how ions would arrange themselves in a salt crystal.

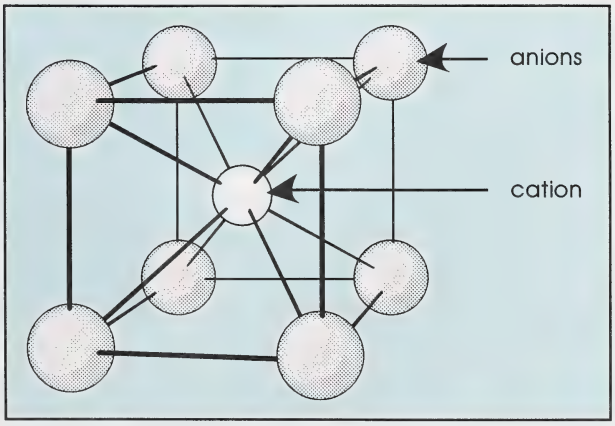


Note: The dotted lines do not imply a physical attachment of ions; they merely show the shape of the crystal.

5. List four characteristics or properties that result from the strong attraction between ions in a crystal.
6. How can an ionic compound be made to conduct electricity?
7. What determines the many different shapes of various ionic compounds?

Check your answers by turning to the Appendix, Section 2: Activity 3.

If you were asked for the chemical formula of table salt, you would know to write NaCl. Even if you were asked to write the chemical formulas for chalk and lye, you may know the formulas are $CaCO_3$ and NaOH. But would you be able to describe the shape of salt, chalk, or lye crystals? Do the formulas give you any idea of what the crystals look like?



As you have already discovered, each ion of one charge is attracted to all of the surrounding ions of opposite charge. That is why ionic solids are represented by **formula units** rather than **molecular formulas**.

formula unit – the smallest ratio of ions that has a net charge of zero and exists in the same ratio of ions as found in the crystal

molecular formula – the formula that shows how many of each kind of atom are present in one molecule of the substance

But how does the formula unit of an ionic compound relate to its crystal shape?

To learn the answer to the preceding questions, read the section A Model for Ionic Compounds on pages 211-212 of your textbook.

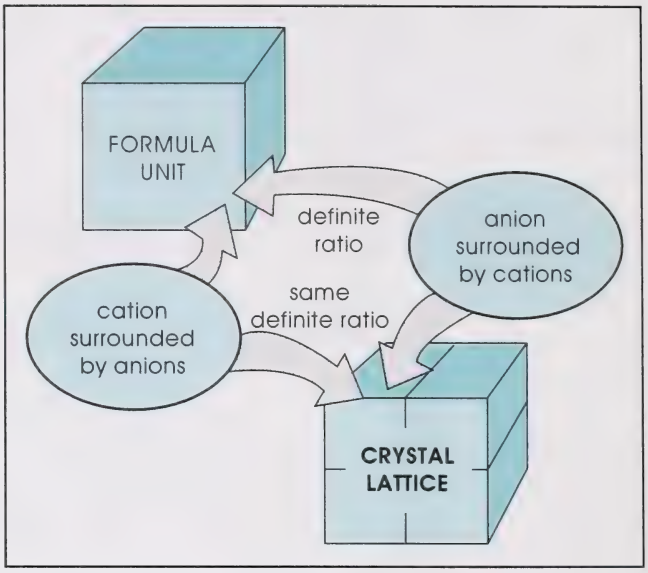
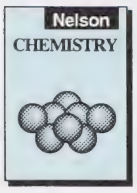


FIGURE 5.10: Relationship Between Fomula Unit and Crystal Lattice



8. a. What is a crystal lattice?

   b. How does a crystal lattice determine the physical properties of an ionic solid?

   c. From the following list, choose the ones that describe properties of ionic solids.

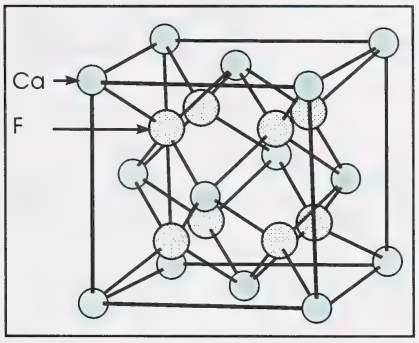
- hard
- ductile
- solid nonconductor of heat and electricity
- solid conducts heat and electricity
- high melting and boiling points
- shiny
- brittle
- malleable
- regular crystal structure

9. How does the formula unit of an ionic compound relate to the crystal lattice shape?

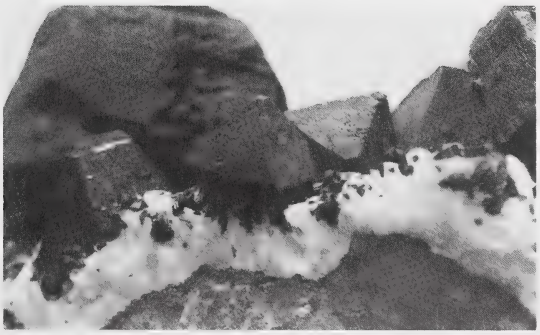
Check your answers by turning to the Appendix, Section 2: Activity 3.

Although ionic compounds have many similar properties, they do not have the same shape. For example, a crystal of salt looks much different than a crystal of quartz. The following photos and diagrams show some of the different crystal lattice structures ionic solids may have.

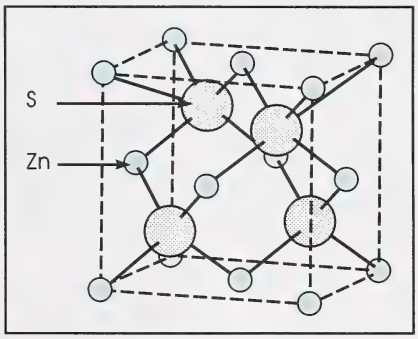
The University of Calgary, (#UC08779). Photo by Greg Verhappen.



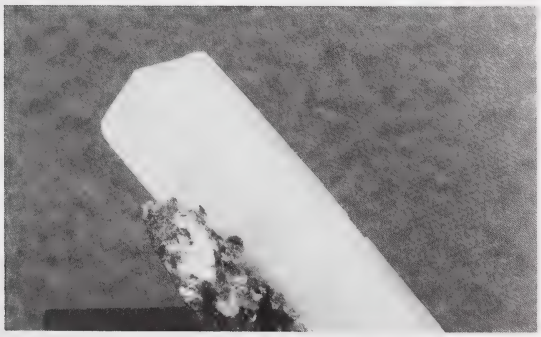
fluorite, CaF_2



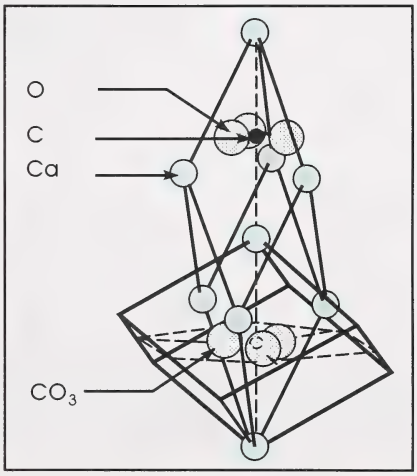
The University of Calgary, (#UC08766). Photo by Greg Verhappen.



sphalerite, ZnS



The University of Calgary, (#UC08577). Photo by Greg Verhappen.



calcite, $CaCO_3$

In the preceding question, you explained that the shape of a crystal is determined by the formula unit of the ionic solid.

To gain a better understanding of how a formula unit is related to crystal structure, carry out the following investigation.

Investigation: Building an Ionic Crystal

Science Skills

- ☐ A. Initiating
- ☐ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☑ F. Evaluating

Carefully follow the directions of this investigation. Pay special attention to the required components, safety aspects, and applied science skills.

In this investigation, you will build a model of a crystal of sodium chloride, NaCl, and relate the model to its formula unit and actual crystal structure.

Materials

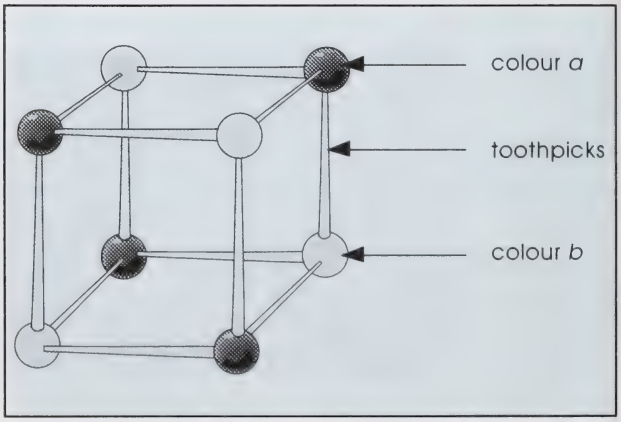
- 450-g bag of small, multi-coloured, soft jelly candies (ju-jubes or gumdrops)
- box of toothpicks
- a few crystals of table salt, NaCl

Procedure

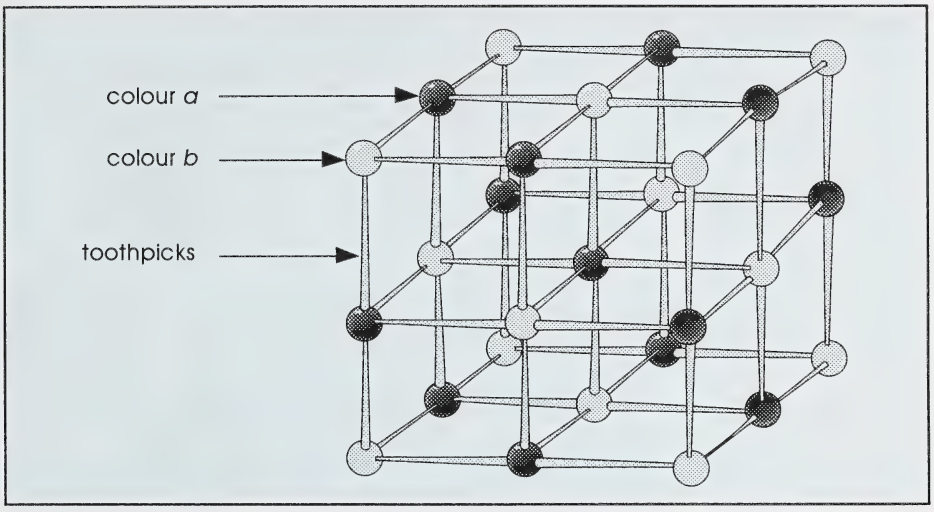
- Separate the jelly candies by colour. Let one colour represent the cations (sodium) and another colour represent the anions (chloride). You will need 24 candies of each of these colours.

  If this is not possible, group the yellow and green candies together in one colour group and the red and black together in another colour group. This will provide the best contrast between the anion and cation colours.

- Build a cube with your candies as shown in the diagram on the right. Make sure that the different colours alternate as shown.



- Using toothpicks, attach anions (colour *a*) to cations (colour *b*) until the model looks like the following diagram. You will have to be very careful in your construction so that the structure will not fall apart.



- Continue adding candies to your model until you have none left.

10. What is the formula unit for the crystal you have constructed?

11. a. What is the final shape of the crystal model you built?

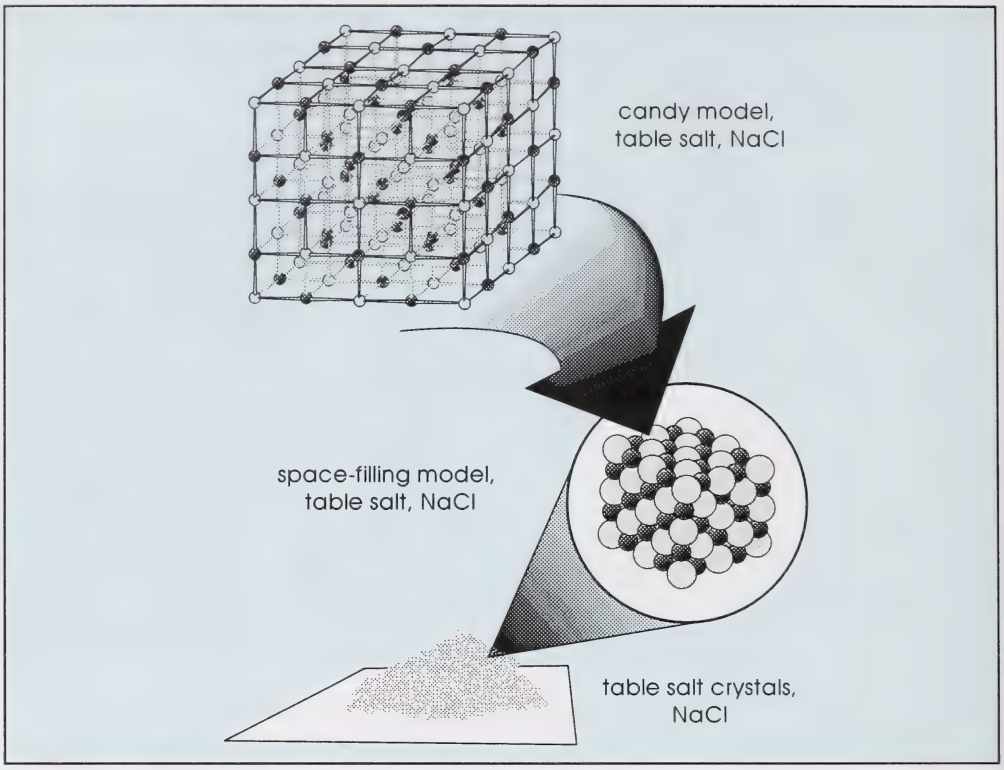
    b. How does this shape correspond to the shape of a salt crystal from your salt shaker?

12. The number of chloride ions in the middle of the crystal that surround each sodium ion is _____, while the number of sodium ions that surround each chloride ion in the crystal is _____.

13. Explain why the crystal model you built corresponds to its formula unit.

Check your answers by turning to the Appendix, Section 2: Activity 3.

Look again at the salt crystal you built and at the crystal of salt from your salt shaker. Can you imagine the ions packed into the small space of that tiny crystal?



DID YOU KNOW?

There are roughly 3×10^{18} ions of sodium and chloride in each crystal of salt, NaCl. If you thought of each ion as the size of a person, the people in one crystal would fill about 5×10^{13} Commonwealth Stadiums (Edmonton, Alberta) using the available seating. That's 50 trillion (50 000 000 000 000) stadiums! How many people would that be?

Can you imagine the ions packed differently when you look at an emerald or other gemstone? The next time you examine a crystalline rock formation or a gemstone, ask yourself how the crystal's shape relates to its formula unit.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

Ionic compounds occur in formula units. A formula unit is the simplest ratio of ions that is used as a building block for the entire ionic crystal. The net charge on a formula unit is always zero.

1. Identify which of the following are the correct formula units of ionic compounds. (Assume the most common ions of metals are used.)

   - $CaCl_2$
   - Mg_2O_2
   - H_2O
   - LiF
   - $SrCO_3$
   - $Fe_3(PO_4)_3$
   - Al_2O_3
   - Cu_2SO_4
   - $Ni_2(SO_3)_3$

2. Identify each of the following statements about ionic crystal lattice structures as true or false.

   a. The shape of crystal lattice structures depends on the sizes and charges of the ions.

   b. All crystal lattice structures have the same basic shape as the sodium chloride crystal lattice.

   c. In a crystal of an ionic solid, the ratio of cations to anions is the same as that of the formula unit.

   d. In a crystal lattice, cations are arranged to be as far apart from each other as possible.

   e. In a crystal lattice, anions are arranged to be as close to as many cations as possible while being as far from as many anions as possible.

3. Why are there many different possible crystal shapes?

4. The formula unit for aluminium oxide is Al_2O_3. Use Figure 5.11 to help you explain why this is the correct formula unit.

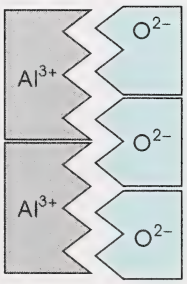
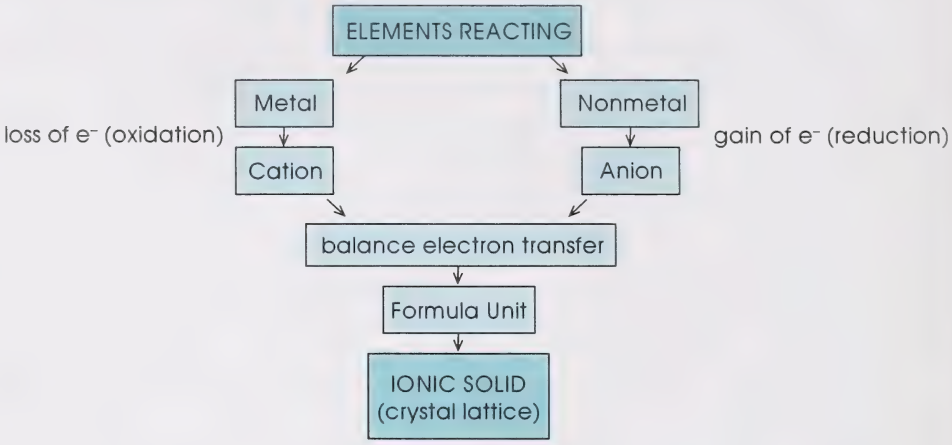


FIGURE 5.11: Al_2O_3

When metals and nonmetals react, an ionic substance is formed. In addition, an oxidation-reduction reaction has occurred.

The following diagram summarizes the main ideas of oxidation and reduction.



5. Complete the following table:

Ionic Solid	Oxidized Element	Reduced Element
CaO		
	Na	S
PbO_2		
Cu_3N_2		
	Al	F_2
$FeCl_3$		

Once you can identify which element is oxidized and which is reduced, you can write the balanced oxidation-reduction reactions.

Use the following half-reactions to answer the next two questions.

A. $Fe \rightarrow Fe^{3+} + 3\,e^-$

B. $Cu \rightarrow Cu^{2+} + 2\,e^-$

C. $O_2 + 4\,e^- \rightarrow 2\,O^{2-}$

D. $F^2 + 2\,e^- \rightarrow 2\,F^-$

6. Write balanced equations for the following reactions:

   a. half-reaction A reacts with half-reaction C

   b. half-reaction A reacts with half-reaction D

   c. half-reaction B reacts with half-reaction C

   d. half-reaction B reacts with half-reaction D

7. Explain why the following half-reactions do not react:

   a. half-reaction A does not react with half-reaction B

   b. half-reaction C does not react with half-reaction D

8. Based on your answers from the preceding question, what general statement can you make about the types of ions that must make up an ionic substance?

Check your answers by turning to the Appendix, Section 2: Extra Help.

Enrichment

Do **one** of the following activities.

1. Alberta and Saskatchewan have very high concentrations of salts in the soil. That is why the soil is so alkaline. In fact, near Fort Saskatchewan, salt is mined from the earth. To learn more about salt mining, use current literature to give a general description of how salt deposits form and the various methods used to mine it.

   If the opportunity is available, you may prefer to tour a salt mine to learn this information.

2. Most minerals get their properties from ionic substances. Go to the library to learn what minerals are, how they are classified, and why they maintain their same basic shape when broken. Relate this to what you have learned in this section about ionic substances.

   If the opportunity is available, you may prefer to talk to a geologist and ask him or her to help you answer this question.

3. There are many different fertilizers used in today's society, many of them ionic in nature. Go to the library and research the three most important elements contained in fertilizers. Discuss the primary use of each of the elements.

   If the opportunity is available, you may prefer to discuss this topic with a farmer, horticulturist, or district agriculturalist.

Check your answers by turning to the Appendix, Section 2: Enrichment.

Conclusion

In this section you learned that ionic compounds are more than just the salt you eat. Ionic compounds are present as rust, in cleaners, in fertilizers, and even as some of the gems you can wear. No matter where they are used, they all have regular crystal shapes that are made up of formula units you learned to predict. By using these formula units, you were also able to explain how and why ionic compounds form. These formation reactions can be represented either by electron dot diagrams or by the use of oxidation-reduction half-reactions.

In the next section, you will learn about molecular bonding and some of its properties.

25

Section 2 Assignment: Ionic Bonding

Review the Evaluation information found in the introductory pages of this module.

It is important to number and clearly identify each page with the following information at the top:

Chemistry 20 -- Module 5 Section 2 Assignment Page # Name and ID #

Be sure to write legibly. Leave a wide left margin and number all of your pages.

1. Potassium oxide and magnesium oxide are produced in a reaction.

   a. Write the chemical formulas for these two compounds. **(1 mark)**

   b. Which of these compounds is the most ionic? **(1 mark)**

   c. State the reason for your decision. **(1 mark)**

2. Give two reasons why the alkaline earth metals are less reactive than the alkali metals. **(2 marks)**

3. Reproduce the following fill-in-the-blank questions. Fill in the missing information.

   a. In terms of electron transfer, when a neutral atom becomes an ion with a 2^- charge, the process of _____ has occurred. **(1 mark)**

   b. In a balanced oxidation-reduction reaction, a total of 15 electrons are transferred. If the anion charge is 3^-, then the cation charge is _____. **(1 mark)**

   c. An ionic crystal of unknown formula M_xQ_y contains 2.11×10^{20} cations of M and 4.22×10^{20} anions of Q. The formula unit is _____. **(1 mark)**

4. Use the half-reaction method to balance the following reactions. Show the half-reactions and the resulting balanced equations. **(9 marks)**

   a. $Ag + F_2 \rightarrow AgF$ b. $Cu + N_2 \rightarrow Cu_3N_2$ c. $Cr + O_2 \rightarrow Cr_2O_3$

Science Skills
- ☐ A. Initiating
- ☐ B. Collecting
- ☐ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☐ F. Evaluating

5. To rank three metals (X, Y, and Z) according to their ease of oxidation, a student attached strips of each metal together and put them in a dilute acid solution. In each situation one metal protected the other by cathodic protection. The next day the student recorded the following observations:

Metal Pairs	X:Y	Y:Z	X:Z
Observations	X – corroded Y – no change	Z – corroded Y – no change	X – corroded Z – no change

   a. Rank the metals from most easily oxidized to least easily oxidized. **(1 mark)**

   b. What was the basis for your decision? **(1 mark)**

   c. None of the metals was from Group 1 on the periodic table. If one of the metals was from Group 2, which one would it most likely be? Explain. **(2 marks)**

Response Page Setup

Reproduce the science skills assessment box after your response to this question. Remember to indicate your evaluation of your skill level for each identified science skill. Be sure to include the spaces for teacher assessment.

Self:	A.	☐	B.	☐	C.	☐	D.	☐	E.	☐	F.	☐
Teacher:	A.	☐	B.	☐	C.	☐	D.	☐	E.	☐	F.	☐

6. In the natural world, alkali metals are never found in pure form. Why? **(1 mark)**

7. Describe three properties of ionic compound crystals and the reasons for those properties. **(3 marks)**

SECTION 3

Molecular Bonding

Have you gone shopping for clothes recently? Have you read clothing labels lately? Go to your closet and pick out some of your favourite clothes. What are your clothes made of? Nylon? Acrylic? Polyester? Wool? Most people buying clothes these days are very aware of the various fabrics available. All fabrics, however, are molecular compounds.

In this section, you will examine molecular compounds. You will learn how to draw molecular structures and predict their molecular formulas in various ways. You will also gain experience in building molecular models so that you can better understand the shapes and structures of molecular compounds.

ACTIVITY 1

Is This Substance Molecular?

If you were asked to name several very common substances that exist as molecules, water and oxygen would probably be on that list. But oxygen is an element as well as a molecule because it is found in the diatomic form of O_2.

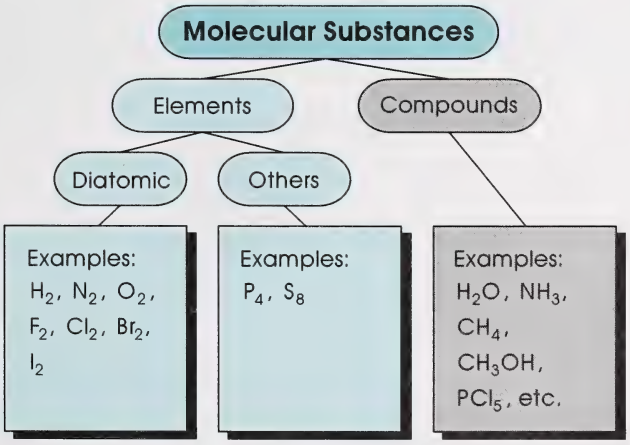
1. What are the other seven elements besides oxygen that form diatomic molecules?

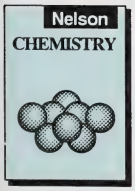
2. a. What types of elements form molecules?

   b. What types of bonds form between the atoms in a molecular element or compound?

Check your answers by turning to the Appendix, Section 3: Activity 1.

The following diagram shows one way molecular substances can be classified.





To learn more about the nature of molecular elements, read Section 8.3: Molecular Substances on pages 213-214 of your textbook.

3. a. Explain why elements such as chlorine and oxygen form diatomic molecules.

   b. What method did the reading use for showing what these molecular elements look like?

4. a. What is a structural diagram?

   b. Draw a structural diagram of F_2.

Check your answers by turning to the Appendix, Section 3: Activity 1.

DID YOU KNOW?

Scientists are constantly finding new bonding and structural arrangements for elements and compounds. A good example is the "Buckyball". If you are interested in this recent discovery, read A Newly Discovered Form of Carbon on page 216 of your textbook.

In addition to elements, Lewis models (electron dot diagrams) and structural diagrams can also be used to show what molecular compounds look like.

To learn how to draw Lewis models and structural diagrams, read the section Explaining Molecular Formulas on pages 219-221 of your textbook.

These rules can be summarized in a diagram as shown in Figure 5.12 on the right.

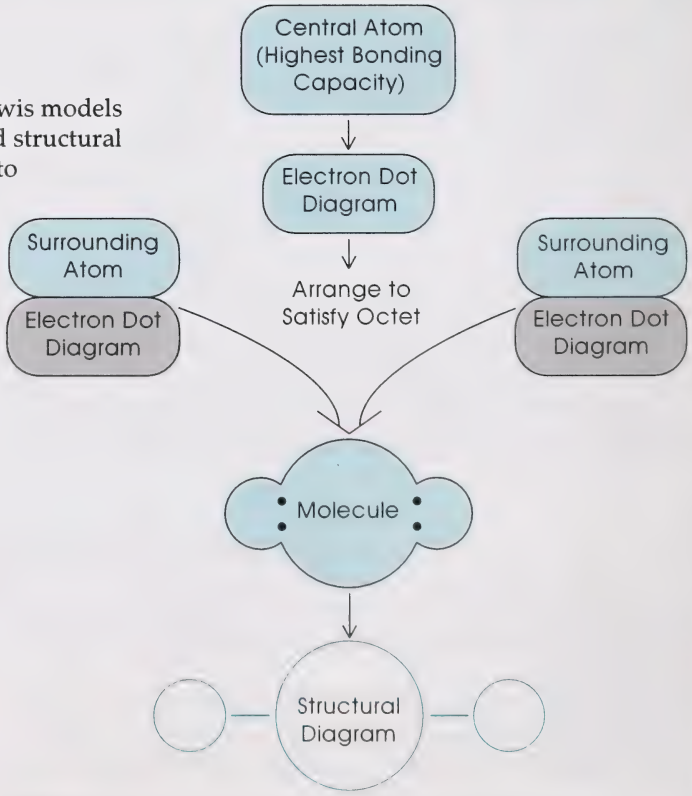
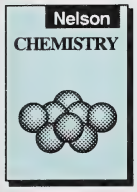


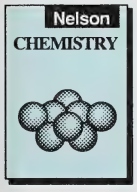
FIGURE 5.12: Drawing Lewis Models and Structural Diagrams



5. Practise drawing these diagrams by doing questions 35 (a-d), 33, 34, and 36 (a-f) from page 221 of your textbook. Complete the questions in the order given. Remember, drawing Lewis models is like building a puzzle. You can't always put the pieces in the first place you try.

Check your answers by turning to the Appendix, Section 3: Activity 1.

You have learned how to draw Lewis models and structural diagrams starting with the number of valence electrons in an atom. Because the diagrams are just models, they have certain limitations.



Look back at the models you drew in the preceding question. Use this information and the information you read on pages 219 to 221 to complete the next two questions.

6. a. List two details Lewis models are able to indicate.

   b. List two details Lewis models do not indicate.

7. Describe what happens to the lone pairs and shared pairs of electrons in a Lewis model when it becomes a structural diagram.

Check your answers by turning to the Appendix, Section 3: Activity 1.

As you have seen, Lewis models help link the valence electrons of an atom to its atomic structure. How do the valence electrons explain why molecular compounds form?

To explain molecular bonds, you need to review the relationship between valence electrons, the formation of bonds, and the octet rule.

8. Complete the following summary of rules that predicts how molecular compounds bond.

   a. What type of valence electrons make the bond?

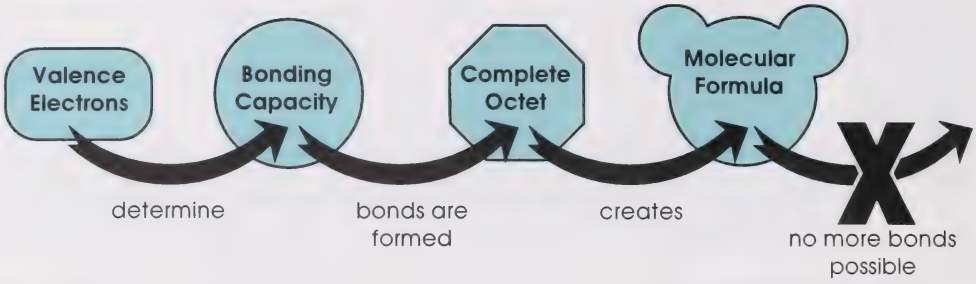
   b. What number of electrons is involved in each bond?

   c. What happens to valence orbitals when bonded?

   d. What is the total number of valence electrons accessed by each bonded atom?

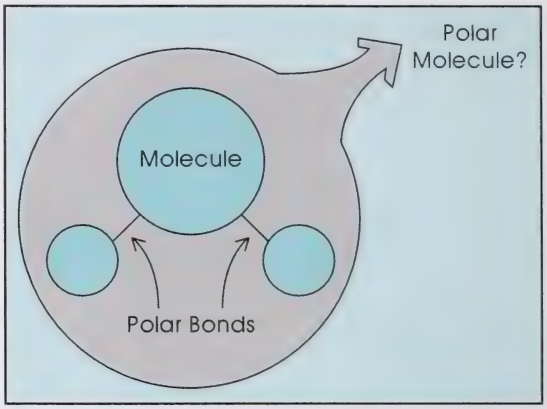
   e. What type of bond is formed?

Check your answers by turning to the Appendix, Section 3: Activity 1.



In molecular compounds, the octet rule is satisfied by atoms sharing electrons in distinct packets called molecules. This differentiates molecular compounds from ionic compounds. You will recall that ionic compounds exist in crystal lattice structures of ions, not individual packets. The octet rule is satisfied in ionic compounds when the ions are initially formed.

In Section 1 of this module, you discovered that covalent bonds can be polar or non-polar. How does the polarity of each bond in a molecule affect the overall polarity of the molecule itself?



A simple example of a non-polar molecule is hydrogen gas, while a simple example of a **polar molecule** is hydrogen chloride.

polar molecule – a molecule in which the electron density on the outer edges of the molecule is unevenly distributed, resulting in parts of the molecule being slightly positive and other parts being slightly negative

Examine Figure 5.13 Electronegativity and Bond Polarity that follows. You will notice that in HCl the electronegativity of chlorine is much greater than hydrogen. Therefore the shared electrons spend more time around chlorine. Chlorine becomes slightly negatively charged and hydrogen becomes slightly positively charged. Whenever an entire molecule gets an uneven distribution of electrons like this, the molecule is said to be polar.

9. Describe an example of equal sharing and unequal sharing in your daily life.

10. Make a generalization that relates electronegativity to the direction of polarity in a polar bond. Give an example.

Check your answers by turning to the Appendix, Section 3: Activity 1.

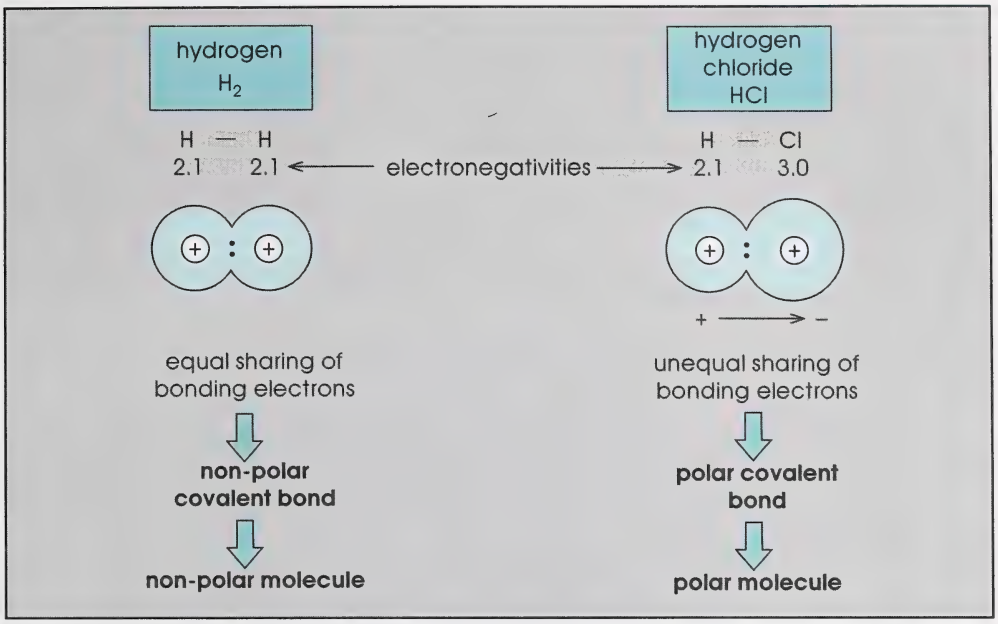


FIGURE 5.13: Electronegativity and Bond Polarity

For molecules containing only one bond, like the preceding examples, the molecule is polar if the bond is polar. However, for molecules containing more than one bond, it is not as easy to tell the molecule's polarity.

Example

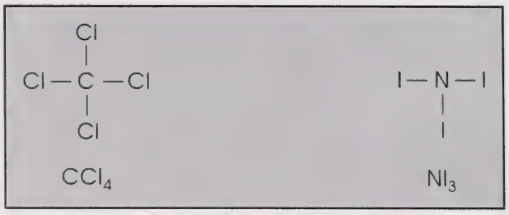
Two molecular compounds that have different properties are non-polar CCl_4, an industrial solvent, and polar NI_3, a compound that explodes fairly easily.

CCl_4 NI_3

11. a. Draw Lewis models of CCl_4 and NI_3.

    b. How do the polarities of the bonds compare?

c. When you look at structural diagrams for CCl_4 and NI_3 as shown on the right, how do the diagrams compare in terms of being **symmetrical**?



symmetrical – having balanced proportions on all sides

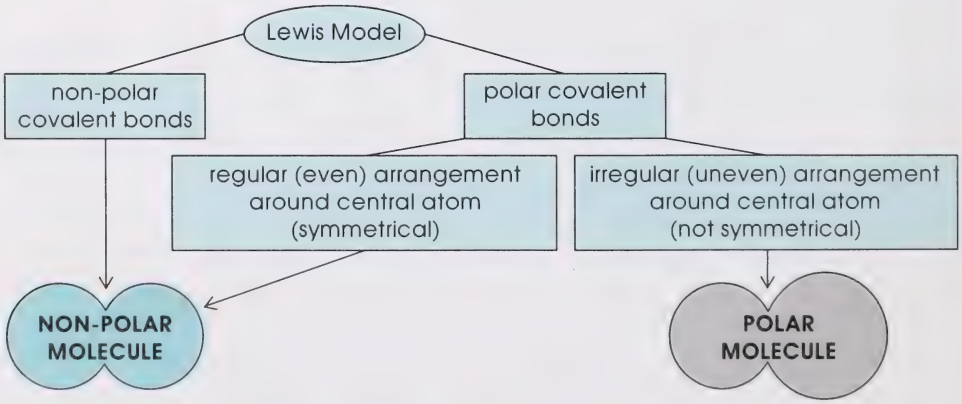
12. a. Based on what you have learned so far, what two factors could explain whether a molecule will be polar or non-polar?

b. If a molecule contains polar bonds, is the molecule itself necessarily polar? Explain.

Check your answers by turning to the Appendix, Section 3: Activity 1.

The polarity of a molecule has a direct bearing on the properties of the substance.

In this course, you are not required to be able to predict polarities of molecules. However, the following diagram shows how bonding concepts can be used very generally to determine the polarity of the molecule rather than just the polarity of a bond.



Molecular substances such as plastic, ammonia, and CFCs (chlorofluorocarbons) exist all around you and come in a variety of shapes and sizes. This is because of the great variety of bonds that elements such as carbon can make. To predict the structures and polarities of larger molecules such as nylon, plastics, and vitamins you follow the basic rules as discussed in this activity. However, predictions are much more difficult because of the numbers of atoms you have to deal with.

For small molecular compounds you have seen that Lewis models and structural diagrams can be easily drawn and it is even possible to predict the polarity of some simple molecules. Being able to predict the polarity of molecules can often give important insights into their properties.

ACTIVITY 2

Molecular Models

AOSTRA

How important is water to you and other life on this planet?

Water is not only important for life on Earth, but for many aspects of science, technology, and society as well. What makes the importance of water so universal?

The properties of water and most other substances originate in large part from their shapes and polarities. Having a general knowledge of the molecular shapes of different substances can help you tremendously in predicting and confirming properties of molecules. In this activity, you will build various molecules with your model kit. This will help you to better understand such things as the interaction of molecules in a chemical reaction.

Nelson CHEMISTRY

To learn about molecular models, read Investigation 8.2 on pages 221-222 of *Nelson Chemistry*.

Investigation 8.2: Molecular Models

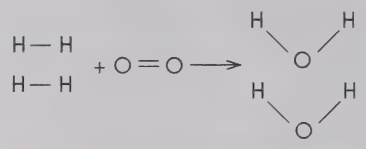
Carefully follow the procedure outlined in the investigation for each of the given chemical equations. Pay special attention to the required components, safety aspects, and applied science skills.

Science Skills

- [ ] A. Initiating
- [x] B. Collecting
- [x] C. Organizing
- [x] D. Analysing
- [ ] E. Synthesizing
- [x] F. Evaluating

Please note that you may have a little trouble when making structures with multiple bonds. Use the springs provided in the model kit for bonds and do the best you can.

1. Record your structures in a data table, similar to the one that follows, for each reaction. An example is done for you.

Example:
Chemical Equation $2\,H_2 + O_2 \longrightarrow 2\,H_2O$
Structures 

2. a. What was always conserved in each of the chemical reactions?

   b. When building the molecules of the product, why did you join all the atoms together with single bonds before making double bonds?

   c. How would a triple bond be represented in a molecular model?

3. Did your method of model building seem as logical, consistent, and simple as possible? Explain.

Check your answers by turning to the Appendix, Section 3: Activity 2.

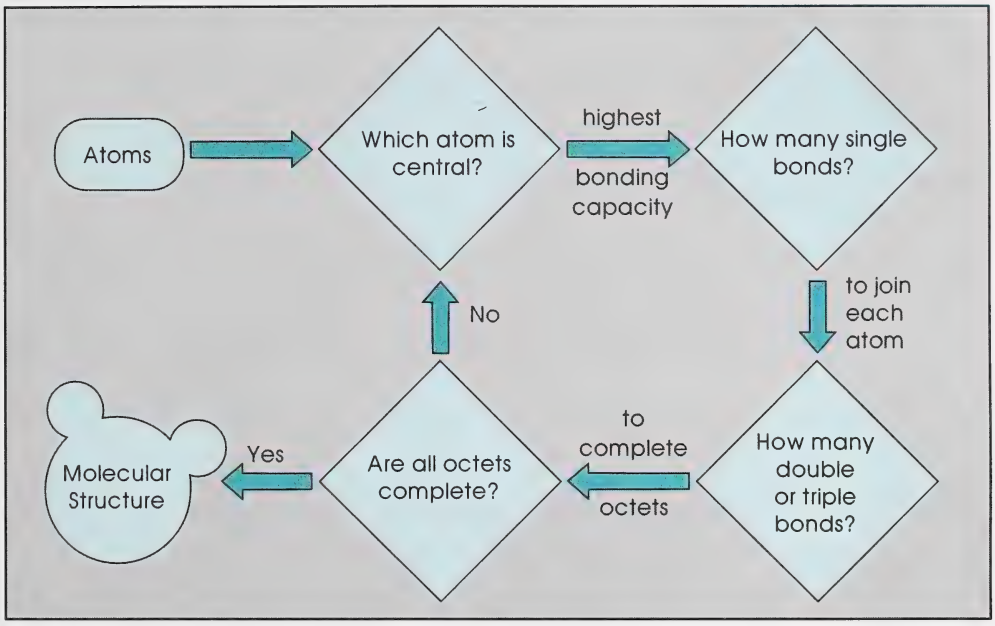
In the preceding investigation, you learned a method for predicting molecular formulas using molecular models. This procedure is summarized in the following diagram.

Notice the diagram involves making many decisions. That is often the case when a chemist is working on a particular molecular structure. Atoms can combine in a number of ways, but the chemist must always remember that usually the correct model is the simplest one that explains all the evidence observed for the substance.

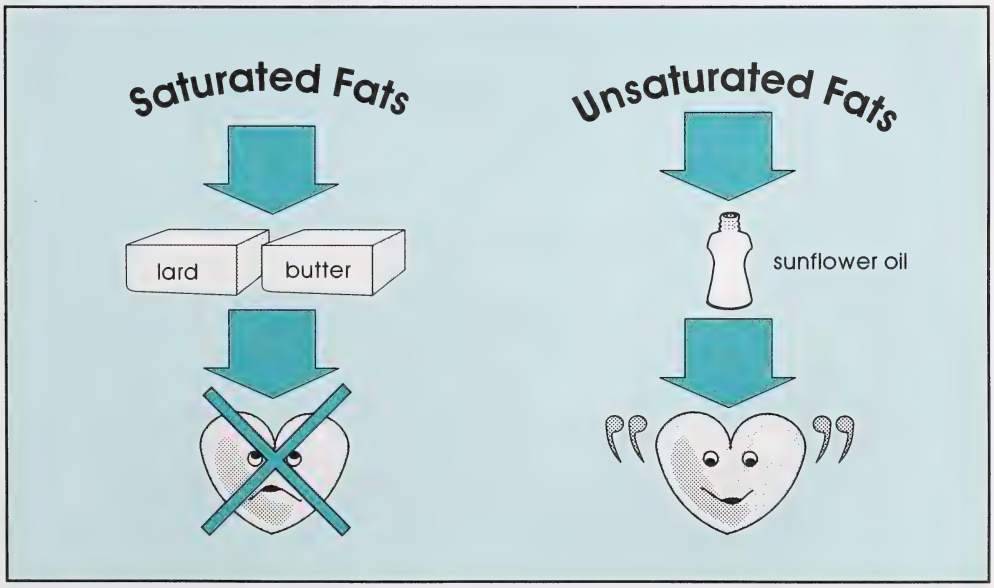
saturated – having only single carbon-carbon bonds

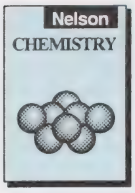
polyunsaturated – having many multiple (double, triple) carbon-carbon bonds

This is even true when talking about the fats in your food. You may have heard that saturated fats are thought to be partly responsible for causing heart disease. Saturated fats can stick to the walls of blood vessels while the polyunsaturated fats usually do not stick.



The presence of a larger number of double bonds in the fat makes it more difficult for the fat to stick to the walls of your blood vessels. Chemists can often use models and the concepts of shapes and bonding for explaining these observations.





How can you tell that double bonds are present in substances such as fats and oils? An experiment that illustrates the presence of double bonds is outlined in Investigation 8.3 on pages 222-223 of *Nelson Chemistry*.

Investigation 8.3: Evidence for Double Bonds

PATHWAYS

If you have access to laboratory facilities, do Part A.
If you do not have access to laboratory facilities, do Part B.

Part A

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☐ F. Evaluating

Carefully follow the directions given for this investigation. Pay special attention to the required components, safety aspects, and applied science skills. Take special note of the safety precautions outlined in the margin on page 223.

Caution

Try to use at least three substances approved by the laboratory instructor in addition to cyclohexane and cyclohexene.

4. Construct a data table and record your evidence for the investigation.

5. As part of the analysis, explain your results of this investigation.

Check your answers by turning to the Appendix, Section 3: Activity 2.

End of Part A

Part B

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☑ E. Synthesizing
- ☐ F. Evaluating

Carefully read the directions given for this investigation. Pay special attention to the required components, safety aspects, and applied science skills. Take special note of the safety precautions outlined in the margin on page 223.

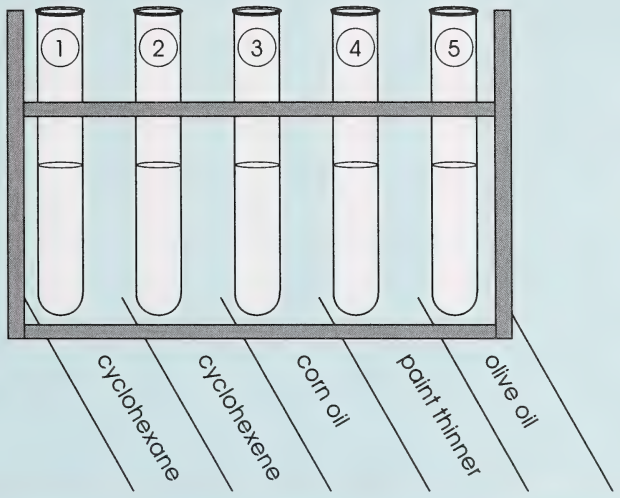
6. a. Prepare a data table that will allow you to record your results.

   b. Instead of performing the lab, use the following diagrams which illustrate the observations in the investigation. Record the observations in the data table you have prepared.

Evidence

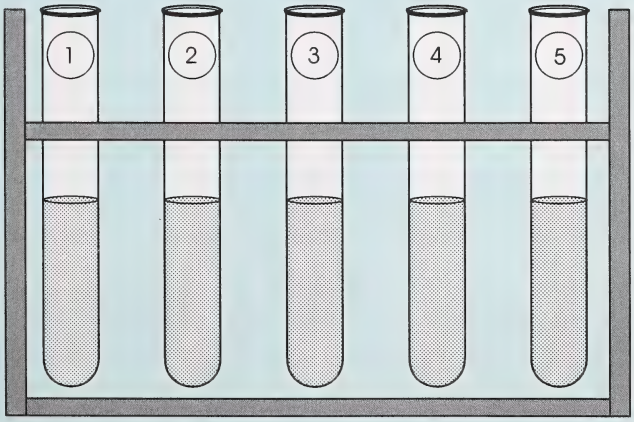
A

before bromine addition

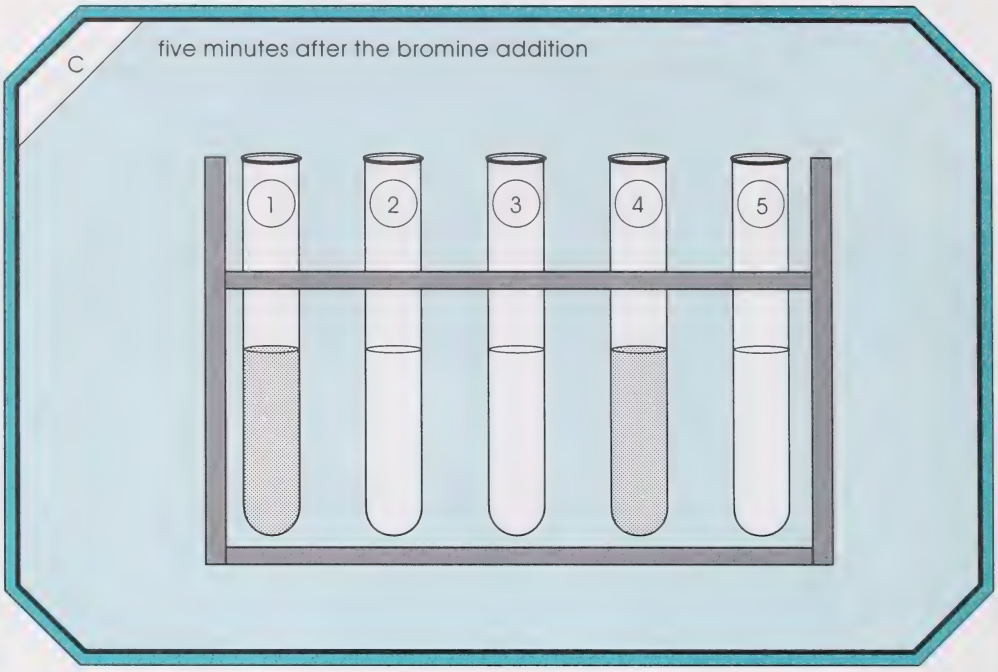


B

immediately after the addition of bromine



Note: The grey shading represents the presence of the red-brown colour of bromine.



7. As part of the analysis, explain the results of this investigation.

Check your answers by turning to the Appendix, Section 3: Activity 2.

End of Part B

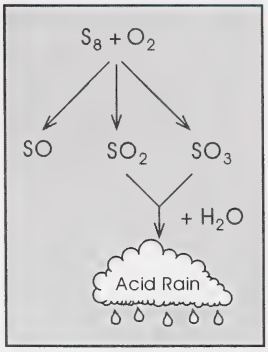
8. a. A friend did the preceding investigation using bacon fat as one of the materials tested. The friend noticed that after the bromine had been added, the bromine colour remained. Use this information to predict whether bacon fat has double bonds or only single bonds.

   b. Why is bacon fat considered more of a health risk than vegetable oils, especially for people with circulatory and heart problems?

Check your answers by turning to the Appendix, Section 3: Activity 2.

You know how to draw Lewis models and structural diagrams for many molecular compounds, but can these models be used to predict the structure of every compound?

For example, the formula for oxygen is O_2. If sulphur and oxygen were to combine together, you might expect $SO_{(g)}$ to form, but experiments show that this doesn't happen. In fact $SO_{2(g)}$ and $SO_{3(g)}$ are produced. These are two components of gases that produce acid rain.



Nelson CHEMISTRY

You may also recall that, as was mentioned on the middle of page 220 of your textbook, nitrogen monoxide did not appear to follow the octet rule. This is one of the limitations of the Lewis model as presented. The following information summarizes a few other examples of limitations of the simple Lewis model.

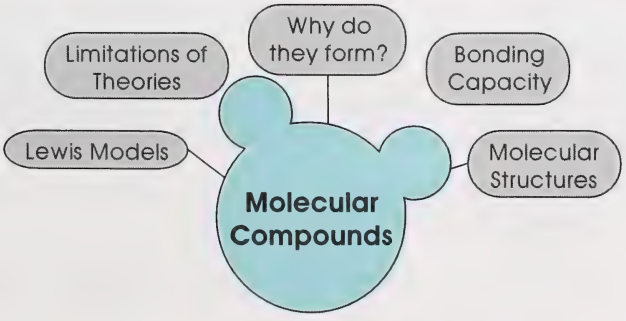
Some limitations of the present bonding theory used include the following:

- The structures of common gases such as SO_2 and SO_3 (produce acid rain), NO_2 (produces smog), and O_3 (ozone) cannot be clearly explained.
- Special properties of some gases like oxygen gas are difficult to explain.
- The formation of many complex ions such as nitrate, nitrite, carbonate, phosphate, and sulphate are difficult to explain.
- The reactivity of the noble gases is difficult to explain.
- Graphite and diamond are different structural forms of carbon. Reasons for the variety in structures are difficult to explain.

9. a. Of the five limitations listed in the preceding summary, the first four break the same rule of bonding. Which rule of bonding is broken?

   b. If bonding rules can be broken does this mean the rules that you have learned are poor ones? Why or why not?

Check your answers by turning to the Appendix, Section 3: Activity 2.



Covalent bonds are found in many things such as your hair, your clothes, plastics, and other synthetic products such as Teflon®.

Lewis models illustrate the structure of simple molecular compounds. These models show that the bonding capacity of an atom depends on the number of valence electrons of the atom and the completion of the valence shell of the atom.

The concepts involved with ionic and molecular substances are summarized in the following diagram.

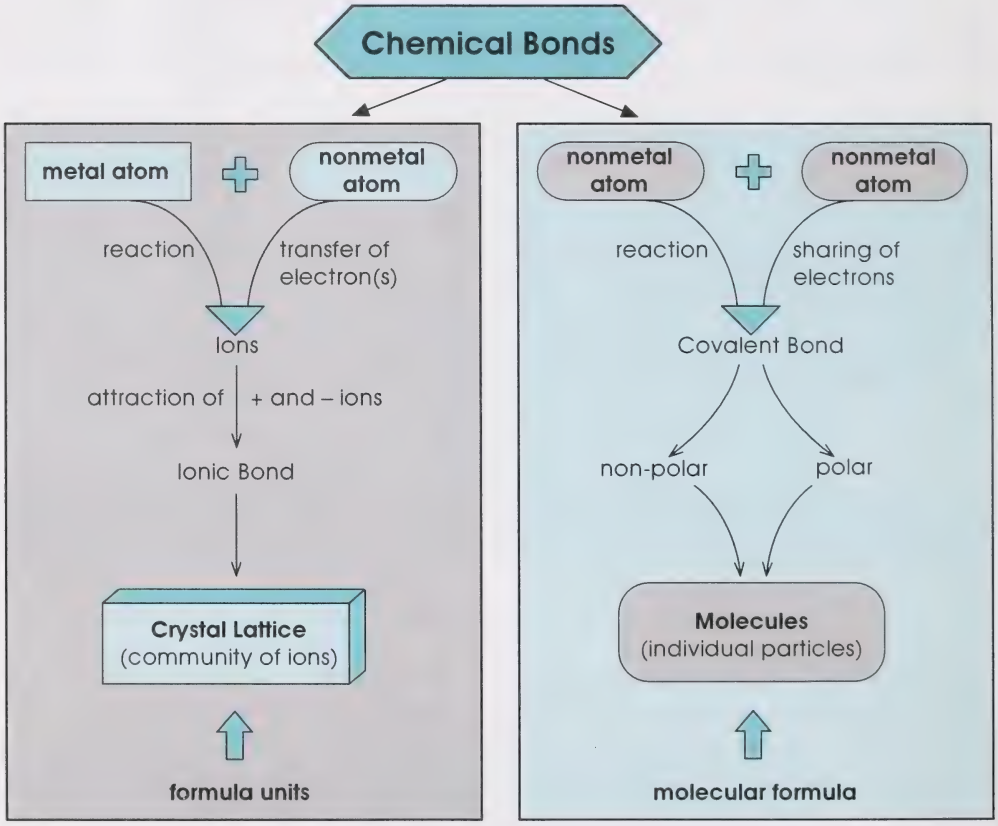


FIGURE 5.14: Ionic and Molecular Summary

Remember the following:

- Formula units and molecular formulas look similar (both contain element symbols and subscripts), but do not represent the same type of structure.
- Formula units represent the simplest whole number ratio of ions in an enormous grouping of ions called a crystal lattice.
- Molecular formulas represent individual distinct packets called molecules.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

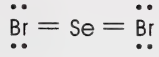
The structure of molecular compounds is determined using Lewis models (electron dot diagrams) or structural diagrams. When drawing Lewis models, the goal is to have each atom attain a complete octet.

1. Decide whether the following Lewis models are correct or incorrect for the compound given. If the model is incorrect, redraw it correctly.

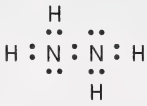
a. O_2

b. PF_3

c. $SeBr_2$

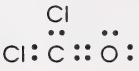


d. N_2H_4



e. C_2H_4

f. $COCl_2$



To change a Lewis model of a molecule to a structural diagram, remember the following:

- Change the bonding electron pairs between the atoms to lines.
- Do not draw the lone pairs because they become invisible.

2. Convert each of the following Lewis models to structural diagrams.

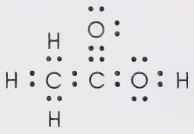
a. CI_4

b. COF_2

c. N_2Cl_4

d. C_2H_2

e. CH_3COOH

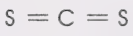


f. HCN

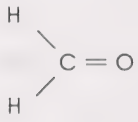
From structural diagrams, you can use the bond polarities and the symmetry of the molecule to predict whether the molecule is polar or non-polar.

3. Use the following molecular diagrams to determine whether the molecule is polar or non-polar.

a. CS_2

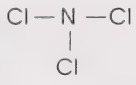


b. H_2CO

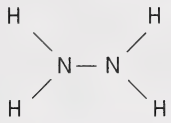


c. SeF_2

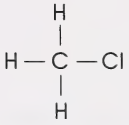
d. NCl_3



e. N_2H_4



f. CH_3Cl



The largest limitation to the molecular model theories discussed in this section concern the octet rule.

4. All of the following molecules exist, but some do not obey the octet rule. Identify the substances from the following list that do not obey the octet rule. (Hint: Draw Lewis diagrams for each to make your decision.)

- CF_4
- NO_2
- XeF_6
- PCl_5
- CSe_2
- SCl_2

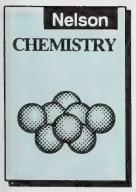
Check your answers by turning to the Appendix, Section 3: Extra Help.

Enrichment

Do **one** of the following activities.

1. What does the term *carbon fibre* mean to you? Skis? Tennis racquets? Automobiles? Planes? Carbon fibres are just one of a new type of material called a composite. Go to the library to discover what composite materials are and where they are used. Discuss the special properties of composites and how they relate to what you learned about molecular bonding.

2. If you were asked to name something made with ceramics you would probably mention a piece of pottery, a kitchen or bathroom tile, or maybe a vase. But modern ceramics are used in many other places as well. Go to the library to discover what modern ceramics are and where they are used. Discuss the special properties of new ceramics and how they relate to what you learned about molecular bonding.



3. You have learned how to draw simple molecular formulas. How do scientists determine these formulas? One way is by use of a mass spectrometer and combustion analysis. This procedure is summarized on pages 215 to 219 of *Nelson Chemistry* in the section Empirical Molecular Formulas. Use the information from this source and from others to describe how a scientist can determine the actual molecular formula of a compound.

Check your answers by turning to the Appendix, Section 3: Enrichment.

Conclusion

You have learned how to draw molecular compounds using Lewis models and how to use these models for predicting whether a molecule would be polar or non-polar. You were able to explain how molecular formulas were created and how to use the bonding theories for developing molecular models. However, you also learned that the bonding theories explored in this unit have limitations, especially by the fact that not all atoms bond to complete their octet.

20

Section 3 Assignment: Molecular Bonding

Review the Evaluation information found in the introductory pages of this module.

It is important to number and clearly identify each page with the following information at the top:

Chemistry 20 – Module 5 Section 3 Assignment Page # Name and ID #

Be sure to write legibly. Leave a wide left margin and number all of your pages.

1. Draw Lewis structures for the following molecules. **(5 marks)**

   a. CI_4

   b. C_2H_6

   c. H_2CS

   d. C_2F_2

   e. HNO_2

2. Briefly explain the limitations of the bonding theory and octet rule as discussed in this section, using NO_2 as an example. **(1 mark)**

3. Explain, using bonding concepts, why molecular compounds can exist in individual molecules, while ionic compounds must exist as ions bonded together. **(6 marks)**

4. On your response page, write the missing part that completes each of the following statements. **(3 marks)**

   a. When phosphorus has one lone pair of electrons, it must have a bonding capacity of _____.

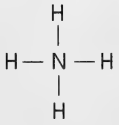
   b. An element has three lone pairs of electrons and is found in the second period of the periodic table. It also has one bonding electron. The element's name is _____.

   c. When PH_3 forms, the type of bonding in the molecule is _____.

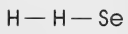
5. In the molecular compound NOF, nitrogen is bonded to only two atoms and still has a complete octet. Explain how this is possible. **(1 mark)**

6. Each of the following structural formulas is drawn incorrectly. Redraw them making the necessary corrections. **(4 marks)**

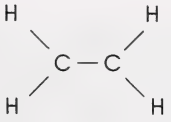
   a. Hydrogen reacts with nitrogen.



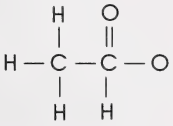
   b. H_2Se



   c. This carbon compound reacts with bromine.



   d. CH_3COOH is produced in an organic reaction.



SECTION 4

Bond Strength and Applications

Imagine what life would be like without friction of any kind. You would be able to glide effortlessly from one place to another like skaters on ice. Or would you? With no friction, you wouldn't be able to push off to start moving because you would slip everywhere. And if you did get started, you wouldn't be able to turn corners while walking or driving your car. In fact, you wouldn't be able to stop unless you ran into something bolted down. But what causes friction? Also, why does it take so much work to unstick something once it is stuck together?

In this section, you will learn what bonding forces cause friction and why it takes so much energy to unstick things once they have stuck together. You will also learn why it takes energy to do things like bake a cake and how you can get this energy by burning natural gas. Finally, you will learn the processes involved in helping scientists develop new compounds such as polytetrafluoroethylene (Teflon®) that helps keep food from sticking, or medications that help keep you healthy, or new sports equipment that help keep you in shape.

ACTIVITY

1 Bond Energy and Strength

Take a scrap sheet of paper and rip it. Look closely at the paper edges. Do you see the little filaments of paper along the torn edge? Now take a piece of plastic that is just as thick and rip it. When you tore that, what happened to the plastic? Which took more effort? Which bonds do you think were stronger? Is there a relationship between how strong a bond is and how much energy it takes to break it?

Nelson CHEMISTRY

To find out the relationship between bond energy and bond strength, read Section 8.4: Energy Changes on pages 224-225 of *Nelson Chemistry*. Figure 5.15 illustrates the interrelationship of the terms and ideas as outlined in the reading.

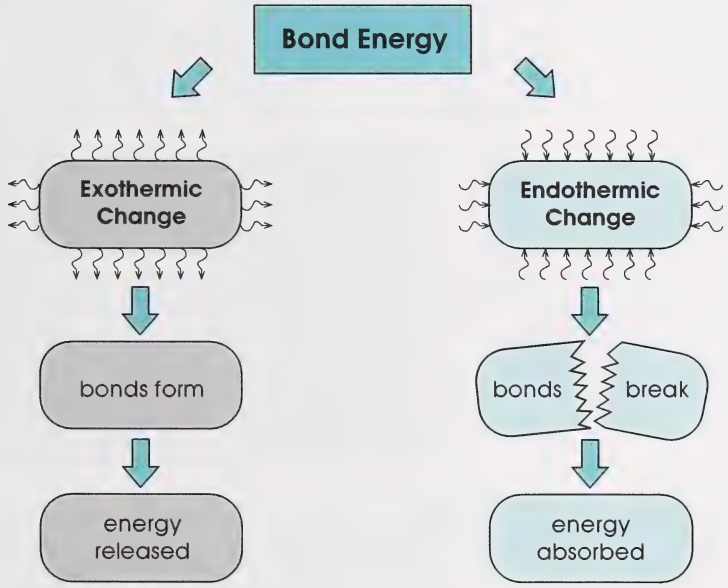


FIGURE 5.15: Bond Energy and Change

To demonstrate your understanding of these concepts, answer the following questions.

exothermic – when energy is given off

endothermic – when energy is absorbed

1. Classify each of the following as an exothermic or endothermic process and indicate whether bonds are being formed or broken.

   a. ice melting in a glass

   b. condensing steam from hot soup

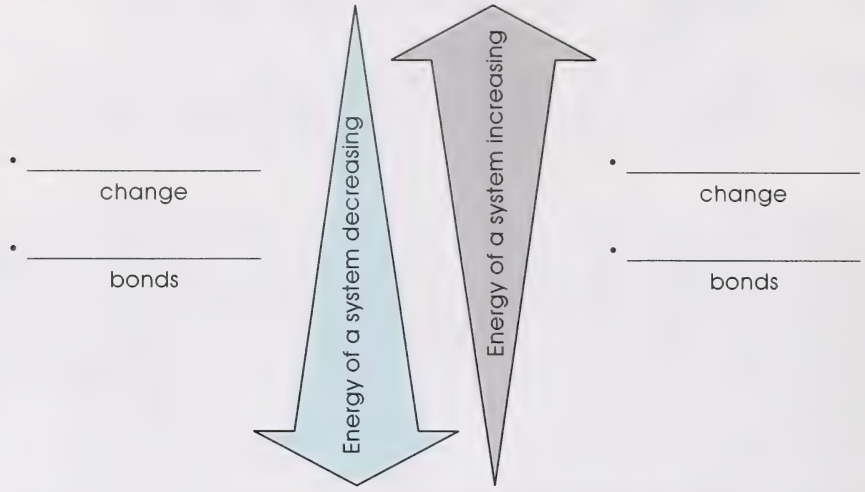
   c. ripping a paper bag

   d. making dry ice (solid CO_2)

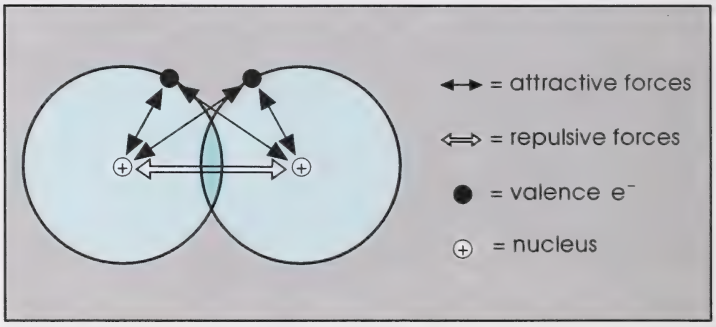
   e. breaking glass

   f. water vapour condensing on grass as dew

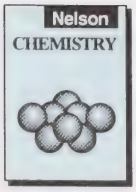
2. Reproduce the following diagram on your own paper and beside each arrow, use the terms from Figure 5.15 to show how these terms relate to the energy changes involved.



3. Explain why it would take energy to break the chemical bond represented by the overlapping orbitals in the given diagram.



Check your answers by turning to the Appendix, Section 4: Activity 1.

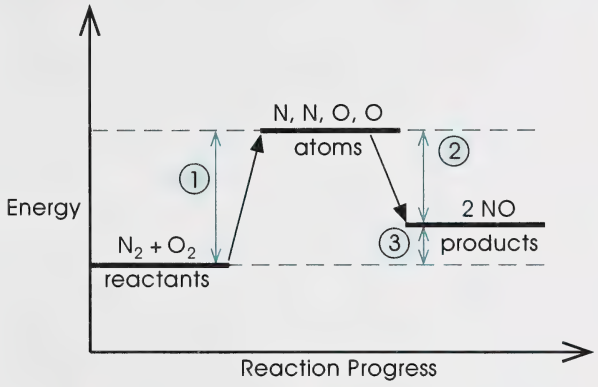


Why is a match needed to start a fire? The reason is because in chemical reactions, bonds need to be broken before they are formed. The energy from the match breaks some of the fuel bonds and starts the reaction. The reacting fuel produces products and extra energy. This extra energy then keeps the reaction going by breaking other fuel molecules. This concept was explained on pages 224 and 225 of your textbook.

Take note of Figure 8.24 on page 225 which gives a diagramatic representation of an exothermic reaction. The following diagram shows an example of an endothermic change as it would appear graphically.

Endothermic Reaction

Example: $N_{2(g)} + O_{2(g)} \rightarrow 2\ NO_{(g)}$



Energy values:

① energy required to break reactant bonds

② energy released when product bonds formed

③ net energy absorbed in overall reaction

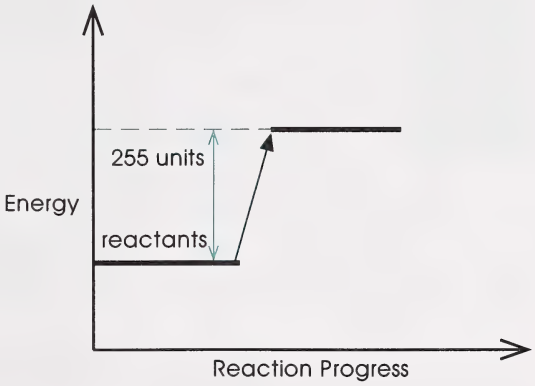
Since ① is greater than ②, the net reaction is endothermic.

4. In a certain chemical reaction, 255 units of energy were added to break the bonds between the reacting molecules and 175 units of energy were released when the new product molecules were formed.

   a. Complete the given energy diagram. Label the various parts of the graph, using previously given information as a guideline.

   b. Calculate the net energy of the reaction, labelling the value on the appropriate area of the graph.

   c. Was the overall reaction exothermic or endothermic? Explain.



5. Identify each of the following situations as being exothermic or endothermic:

   a. reactants + energy → separated particles

   b. separated particles → products + energy

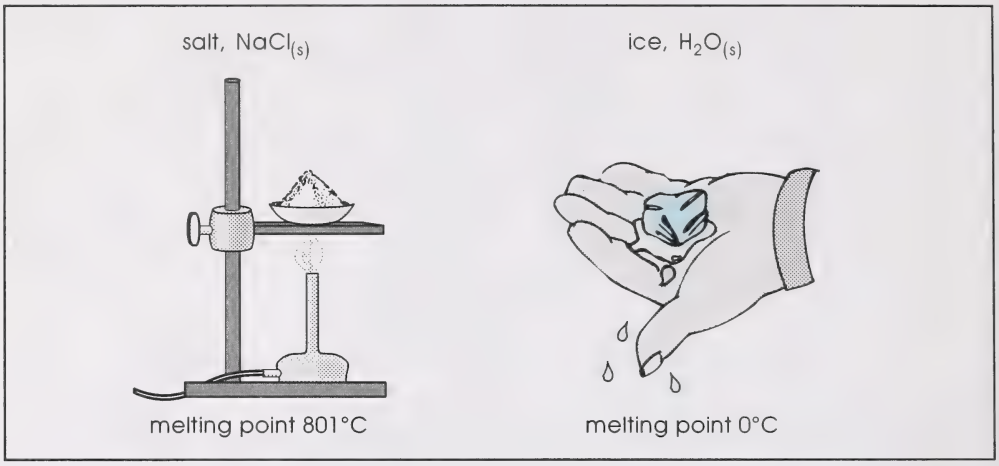
   c. (photosynthesis)
   $6\ CO_{2(g)} + 6\ H_2O_{(l)} + \text{energy} \rightarrow C_6H_{12}O_{6(s)} + 6\ O_{2(g)}$

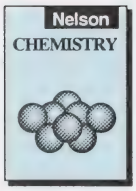
   d. $H_{2(g)} + Cl_{2(g)} \rightarrow 2\ HCl_{(g)} + \text{energy}$

   e. (boiling water) $H_2O_{(l)} \rightarrow H_2O_{(g)}$

6. State a generalization relating the side of a chemical equation the *energy* term is written on to the type of process (exothermic or endothermic).

Melting ice is an endothermic reaction. So is melting a solid like table salt, NaCl. But to melt salt, you need to add considerably more heat energy than you need for melting ice. Why?





The section Relative Strengths of Chemical Bonds on pages 225 and 226 of your textbook explains the relationship between the phases of matter and bond strength, as well as the relationship between covalent and ionic bonds. Read this section to find out about these relationships.

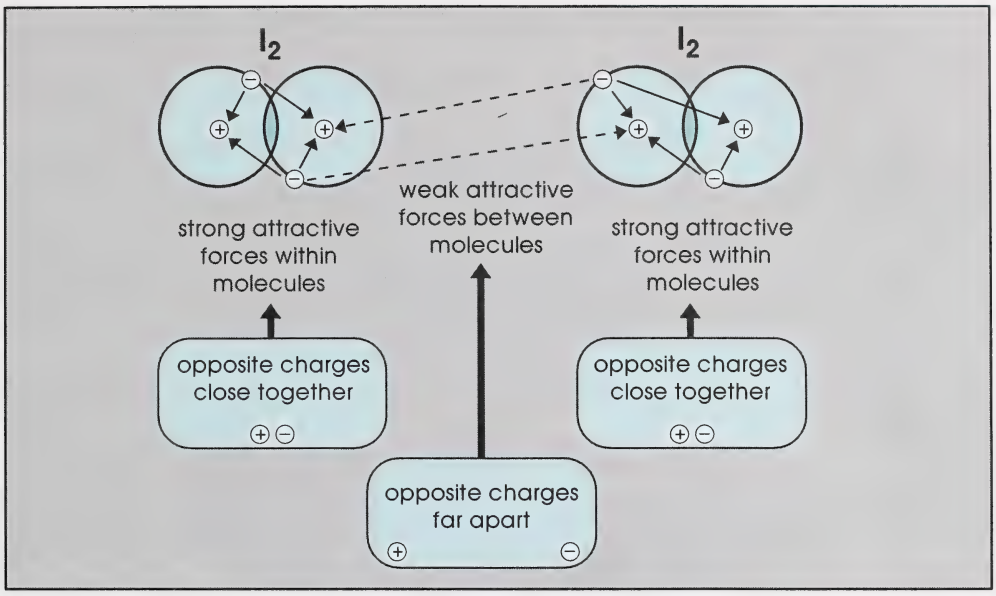
Did you find out why it takes more energy to boil water than melt ice? From what you read, you know that the stronger the bond, the more energy it takes to break the bond, and that each type of bond has a different bond energy.

7. Create a two-column table with the headings **Weak Bonds** and **Strong Bonds**. Group the following terms into the categories of your table.

   - covalent bonds within molecules
   - bonds between solid molecules
   - bonds between liquid molecules
   - ionic bonds within solid crystals

Check your answers by turning to the Appendix, Section 4: Activity 1.

The following simplified diagram indicates where the weak and strong forces of attraction are located for solid iodine molecules.



It is important for you to remember the following:

- All forces of attraction, including ionic bonds, covalent bonds, and forces between molecules, involve an attraction between opposite charges. The strength of these forces is related to the distance between the charges and the size of the charges.
- It takes energy to break any of these attractive forces and energy is released when these forces form. The amount of energy involved is related to the strength of the attractive forces.

From the previous sections, you know how ionic and covalent bonds form to create strong forces of attraction. But what bonding principles allow some molecular compounds, such as water, to occur as liquids while others, such as sulphur, form solids and still others, such as methane, form gases?

ACTIVITY 2

Intermolecular Forces

friction – force of attraction involved when two touching surfaces slide past each other

Rub your hands together briskly. What happens? Why did your hands become hot? Now put a little hand lotion or water on them. Rub your hands briskly together again. Before the liquid disappeared was there a difference in the heat generated? You probably know that **friction** caused the heat when you rubbed your hands together. You also know that friction can be both beneficial and detrimental.

1. a. List three situations when friction is desired.

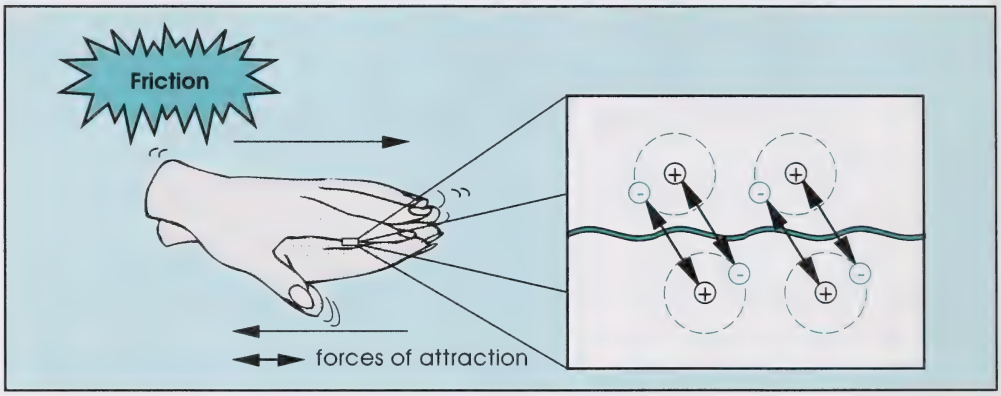
   b. List three situations when friction is not desired.

2. a. State two ways that you could minimize friction.

   b. State two ways that you could increase friction.

Check your answers by turning to the Appendix, Section 4: Activity 2.

From the previous questions, you know that friction can be increased and decreased, but what causes friction?



Electrons (–) in molecules on the surface of one hand are attracted to the nuclei (+) in molecules on the surface of the other hand.

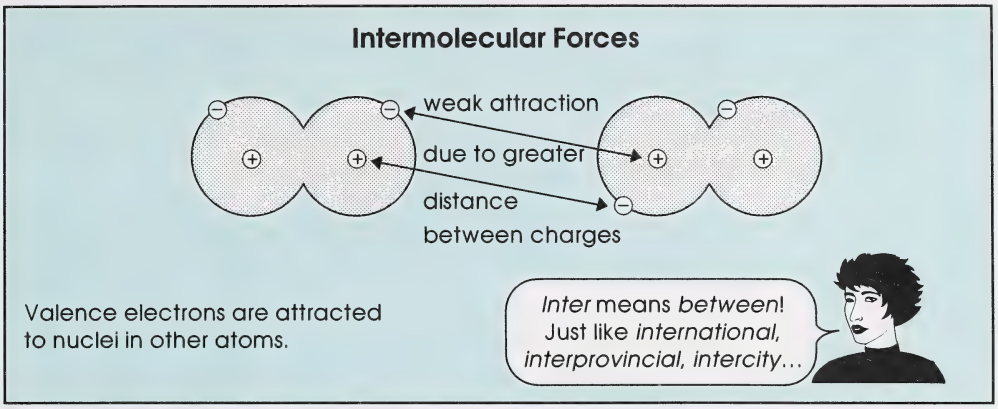
The forces of attraction (weak bonds) break and form continuously.

3. Based on the preceding information and what you learned in Activity 1 of this section, what causes the heat energy you feel when you rub your hands together?

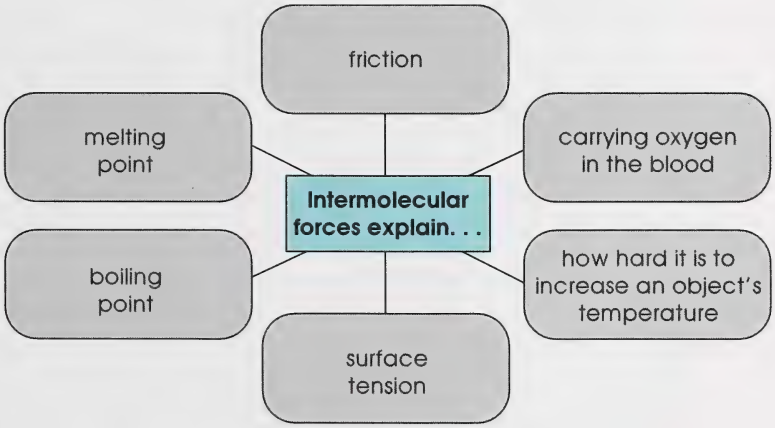
Check your answers by turning to the Appendix, Section 4: Activity 2.

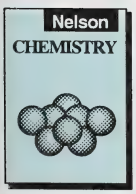
intermolecular force – the weak forces of attraction between molecules

The forces of attraction discussed in the preceding example are called **intermolecular forces**. The idea of intermolecular forces (weak bonds) was introduced at the end of the last activity. These forces are again explained in the following diagram.



Friction is just one example of a process involving intermolecular forces. Intermolecular forces explain many other observations, as illustrated in the following diagram.





To learn how these observations can be explained, use the information from pages 226-230 (top) of your textbook to answer the following questions. Ignore, for now, Investigation 8.4: Evidence for Polar Molecules and Lab Exercise 8D: London Forces.

4. List the three types of intermolecular forces.

5. a. Intermolecular forces are weak because the _____ between the electron of one molecule and the _____ of the other molecule is _____ than the distance between the _____ and nuclei within the molecule.

intramolecular force – the force of attraction between atoms within a molecule

b. The forces within a molecule are called intramolecular forces. These forces (involving sharing of electrons) cause the formation of _____ bonds.

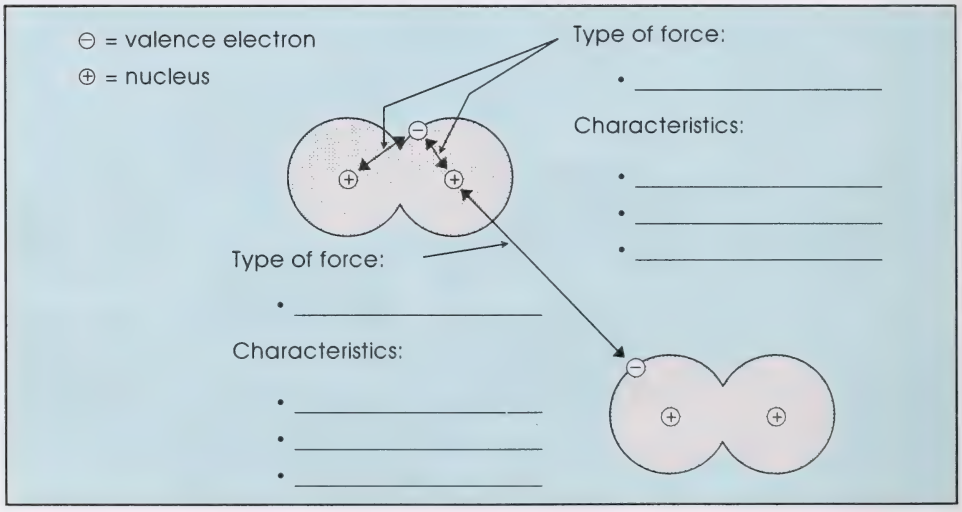
6. a. List two main factors that affect the strength of intermolecular forces.

b. Of these two factors, which one has the greatest effect on the melting points of substances?

7. One way to indirectly determine the strength of an intermolecular force is to look at the molecule's _____ or _____.

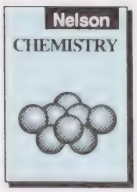
8. Reproduce the following diagram. Identify and describe the parts of the diagram using the following terms and statements. Terms or statements may be used more than once.

- intermolecular force
- intramolecular force
- strong
- weak
- require energy to break
- caused by electron-nucleus attractions



9. Intermolecular forces are also involved when dealing with solubility. When determining the solubility of two substances, a general rule is that _____ substances will mix with or dissolve _____ substances while _____ substances will mix with or dissolve _____ substances. This is summarized by the three word rule: _____ _____ _____.

10. Typically, if two molecules have the same number of electrons, the more _____ molecule will have the higher melting and boiling point. (See Table 8.5 in the margin on page 229 for hints.)

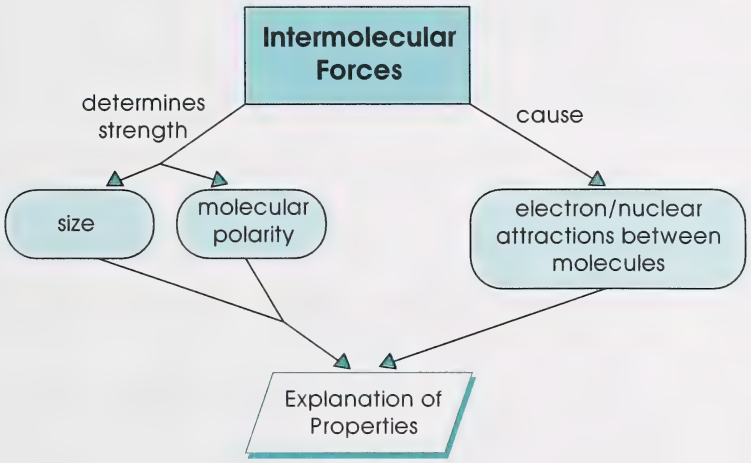


A practical example of the rule "like dissolves like" is in the development of ways for dealing with oil spills.

Frames 28016-28741

If you have access to the laser videodisc *Cosmic Chemistry*, you can see an example of an oil spill.

Find and view the sequence that starts with frame 28016, chapter 21, disc side 2.



You have seen that molecules such as water and hydrogen chloride are polar, and that polarity gives these molecules some special characteristics, especially when intermolecular forces are involved. In the last section, you even predicted the polarities of some molecules. But how can you test to see if molecules are polar or not?

Nelson CHEMISTRY

One way is to hold a charged object near the substance to be tested. A neutral substance will not be attracted to it, but a polar substance will. This is illustrated in Figure 8.27 on page 228 of *Nelson Chemistry*. Read the given explanation before continuing so you will understand the procedure in the following investigation.

Investigation: Showing Molecular Polarity

Science Skills

- [ ] A. Initiating
- [x] B. Collecting
- [ ] C. Organizing
- [x] D. Analysing
- [x] E. Synthesizing
- [x] F. Evaluating

Carefully follow the directions given for this investigation. Pay special attention to the required components, safety aspects, and applied science skills.

Problem

Of the liquids to be tested, which contain polar molecules?

Design

A charged balloon or comb will be held near a thin stream of each of several liquids and the results will be observed.

Materials

- 4 polystyrene or paper cups
- large cooking pot or beaker
- 1 large sewing needle or straightened paper clip
- 75 mL rubbing alcohol or other alcohol
- 75 mL light cooking oil (e.g., sunflower oil, olive oil)
- small balloon or a comb
- cake pan or tray
- paper towel or rag
- 75 mL water
- 75 mL vinegar

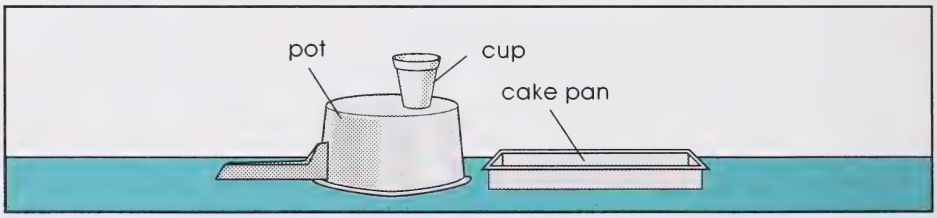
Note: Rubbing alcohol can be obtained from a drug store.

11. Construct a data table and record your results as you carry out the following procedure.

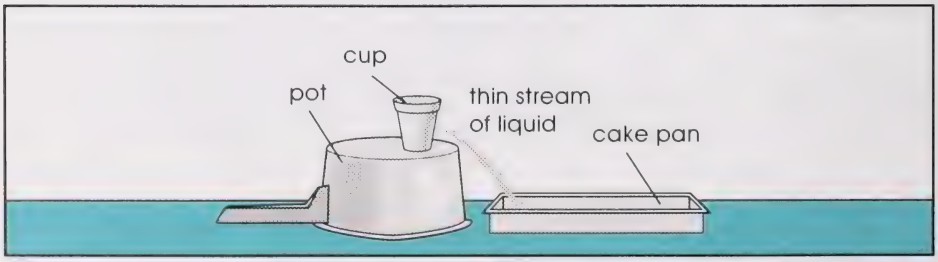
Procedure

- Fill one of the polystyrene cups half-full with water and place it on the inverted pot as shown in the diagram.

- Rub the balloon (or comb) in your hair until your hair sticks really well to the balloon (or comb).

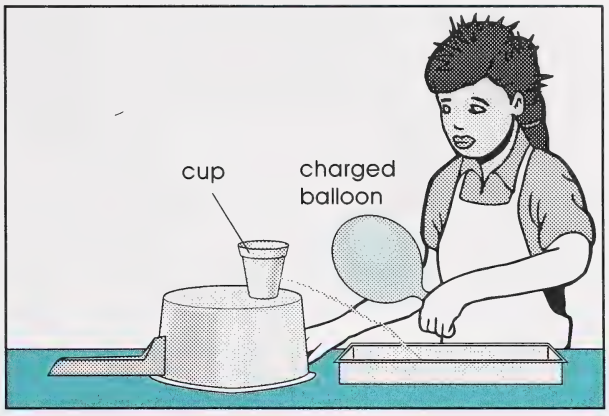


- Using the sewing needle, poke a small hole near the base of the cup so that a thin stream of liquid can pour out.



- Hold the charged balloon (comb) near the side of the stream of liquid and observe. If the balloon (comb) gets wet, you may need to recharge it in your hair.

- Record your observations. Wash the pan after using each liquid. If you use clean equipment, you may wish to return the used material to its original container.



- Repeat the procedure with each liquid until all of the liquids have been tested.

- When you are finished, clean your materials and return them to their original places.

12. Write a brief analysis of your evidence.

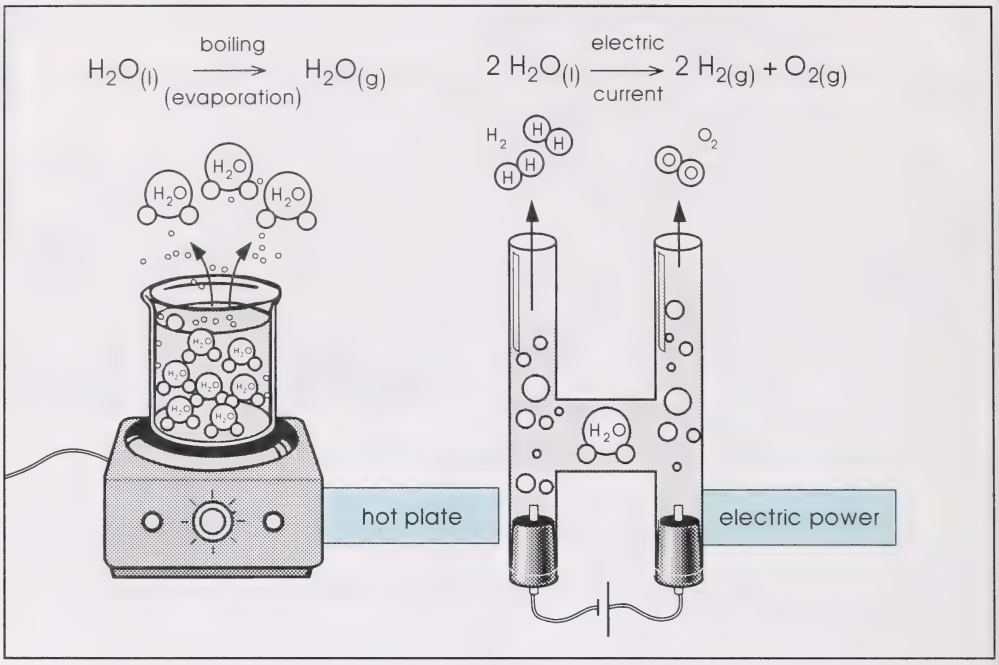
13. a. If another material with an opposite charge to that of the balloon (comb) was used instead of the balloon in the investigation, how would this affect your results?

    b. Why? (Explain your answer to part a.)

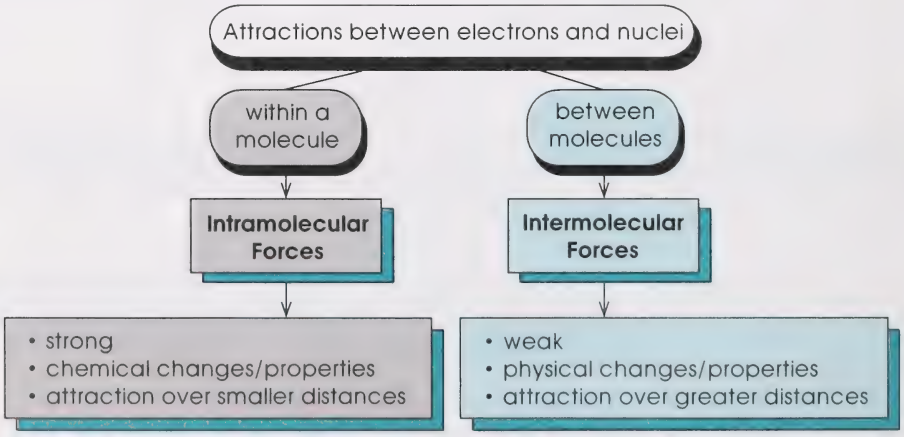
14. One of the liquids tested in the investigation could give misleading results because of a flaw in the experimental design. Read the ingredient labels on the containers of the liquids to decide which material could have given these results. Explain your answer.

Check your answers by turning to the Appendix, Section 4: Activity 2.

Why aren't hydrogen gas and oxygen gas produced when you boil water at a very high stove temperature? If you think about it for a minute, you will note that you need to break covalent bonds to produce hydrogen and oxygen. These intramolecular bonds are much stronger than the intermolecular bonds that are broken to boil the water. The water would never reach a high enough temperature on your stove to break these covalent bonds without first boiling away. Usually water is decomposed by passing an electric current under controlled conditions through the water.



Then what is the relationship between intermolecular forces and intramolecular forces? Do they predict similar things? The following diagram provides a summary.



15. a. In what way are intermolecular forces the same as intramolecular forces?

    b. List at least three ways these forces are different from each other.

Check your answers by turning to the Appendix, Section 4: Activity 2.

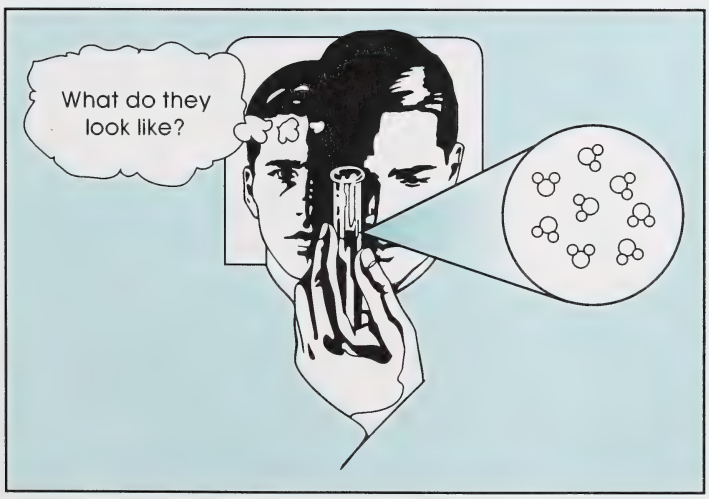
How is friction related to the boiling point of water? After learning about the nature of intermolecular forces and what properties they predict, you know that friction and boiling points are related through the interaction of electrons and nuclei of different molecules. You have also discovered that this information can show how intermolecular forces and intramolecular bonds are related.

ACTIVITY

3 Technology and Applications

Have you ever had a headache that just wouldn't go away, no matter which pain medication you tried? Didn't you wish you had something that would work?

One of the more popular brands of pain relief contains acetylsalicylic acid (ASA). ASA is present in the bark of willow trees. At first, people chewed the bark to relieve pain and flu symptoms, but because of technology, ASA was isolated and eventually synthesized in the laboratory. As an understanding of molecular bonding was gained, scientists began to modify drugs such as these to create newer, more powerful drugs that have fewer side effects.



As technology grows, modifications such as these become easier to do. This is an example of how science and technology work together to advance each other.

Chemists have a major obstacle to overcome in their work that many people do not have in their professions.

1. What is the biggest problem a chemist faces when trying to study a particular atom or molecule?

To overcome this obstacle, scientists use new technology, much of which wasn't available even thirty years ago. The following table summarizes some of the technology that a chemist could use to identify substances.

Technology	Description and Use
mass spectrometer	• determines molar mass of a compound and breaks molecules apart where the intramolecular bonds are weaker
chromatography	• separates one kind of molecule from another using properties like polarity or electrical conductivity
computer	• converts information into useful models to aid understanding • allows positioning and changes to models quickly into easily understandable images • does repetitious measurements or calculations quickly and efficiently • does difficult analyses and calculations quickly and efficiently • allows a scientist to run a hypothesis theoretically before trying the actual experiment
light spectroscopy	• measures and graphs reactions of bonds to certain frequencies of light (Each type of bond reacts differently.)
microscope	• can greatly magnify objects
crystallography	• measures the amount that electron beams bend as they pass through a crystal (The pattern is related to its structure.)
scanning tunnelling microscope	• An extremely fine needle almost touches the surface of a crystal. A slight current passes between the crystal and needle that allows the needle to move minutely up and down as it senses the outer orbitals of individual atoms. • A computer controls the needle and creates an image of what is seen.

mass spectrometer – an analytical instrument, one function of which is to determine the molar mass of a compound

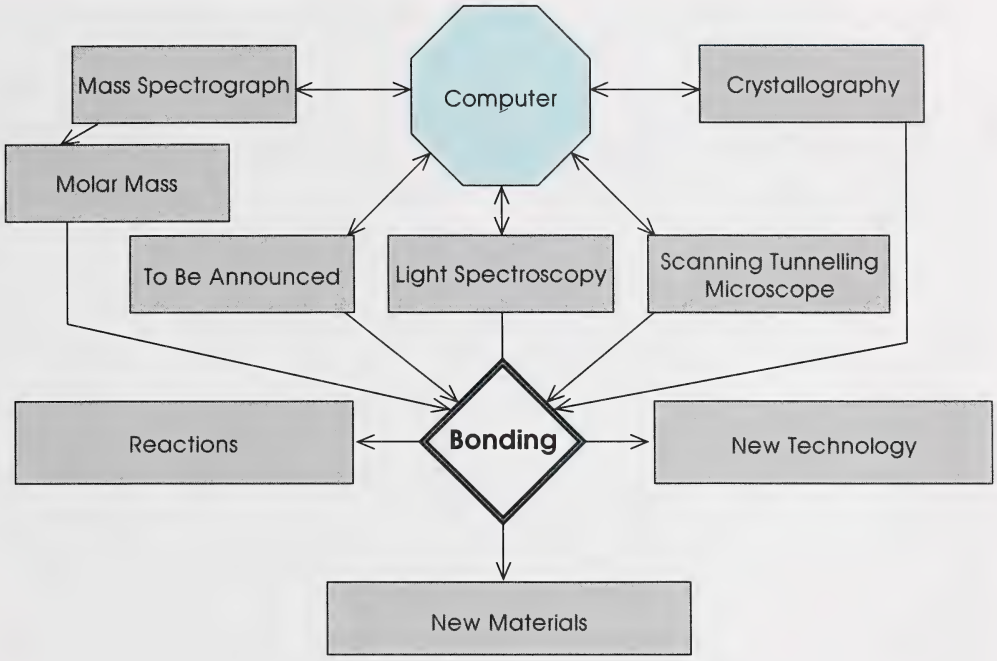
chromatography – separates one kind of molecule from another usually based on molecular polarity

light spectroscopy – using various types of light energy to help in chemical analysis

crystallography – method used to determine the crystal structure of a compound

scanning tunnelling microscope – analytical instrument able to detect individual atoms in certain materials

FIGURE 5.16: Technology Used in Science



2. a. Which of the technologies from the previous table would be least beneficial to a modern chemist? Why?

   b. Which of the technologies from the previous table would be most beneficial to a modern chemist? Why?

3. Which two of the technologies do not directly reveal the forces of attraction and repulsion found within the substance being studied?

4. As technology develops what happens to the ability to detect particle size?

Check your answers by turning to the Appendix, Section 4: Activity 3.

Before the scanning tunnelling microscope was developed, scientists had to use other means to detect molecules. Now they can virtually see them. In fact, scientists have even been able to move individual atoms with this technique.

5. Explain how the scanning tunnelling microscope could affect the following situations in the future:

   a. new drug manufacturing

   b. genetic engineering

   c. an understanding of bonding

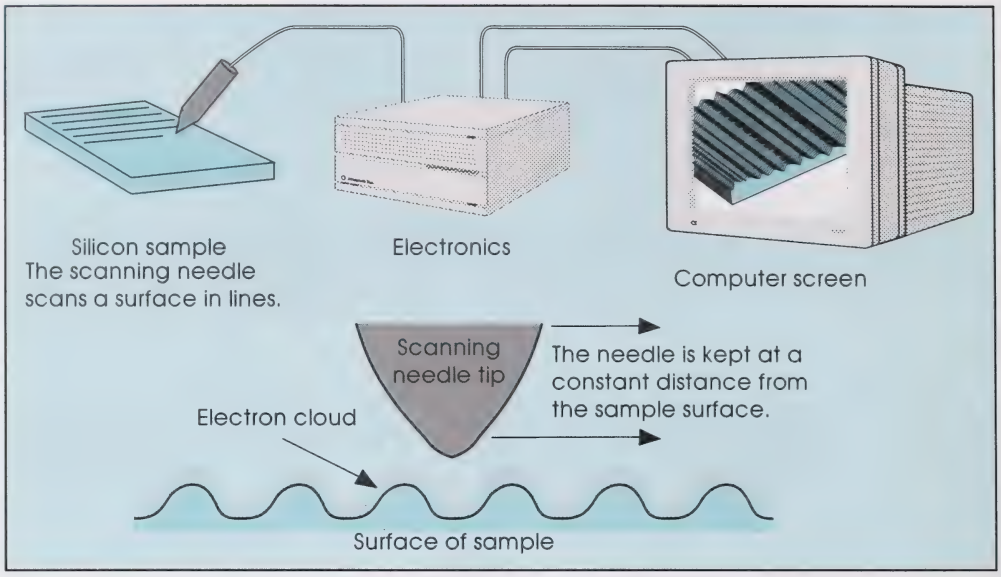


FIGURE 5.17: The Scanning Tunnelling Microscope

6. List two other ways a scientist may wish to use the scanning tunnelling microscope.

Check your answers by turning to the Appendix, Section 4: Activity 3.

Where are computers used in your life? Automated banking machines, calculators, video games, watches, stereos, and automobiles all use computers, and all of these use components that contain silicon.

If you recall, silicon is a metalloid bonded covalently to itself. In the 1950s, the potential uses of silicon were not clearly understood at all. Nor were its properties. This shows how quickly science and technology can advance.

Frames 36037-41961

If you have access to the laser videodisc *Cosmic Chemistry*, you can see how silicon is incorporated into integrated circuits. Find and view the sequence starting with frame 36037, chapter 17, disc side 4.

ceramic – a hard, clay-based material that resists very high temperatures

composite – material made by imbedding or mixing fibres into a plastic or resin base

Besides the computer, an understanding of bonding has helped scientists develop many other new materials. And as these materials develop, scientists are able to learn even more about bonding. One of these materials is ceramic, a clay-based substance that is hard and resists high temperatures. Another class of materials is the composites. Composites are becoming ever more popular because they are light, strong, and flexible.

The following diagram illustrates how science and technology have worked together to develop the modern computer.

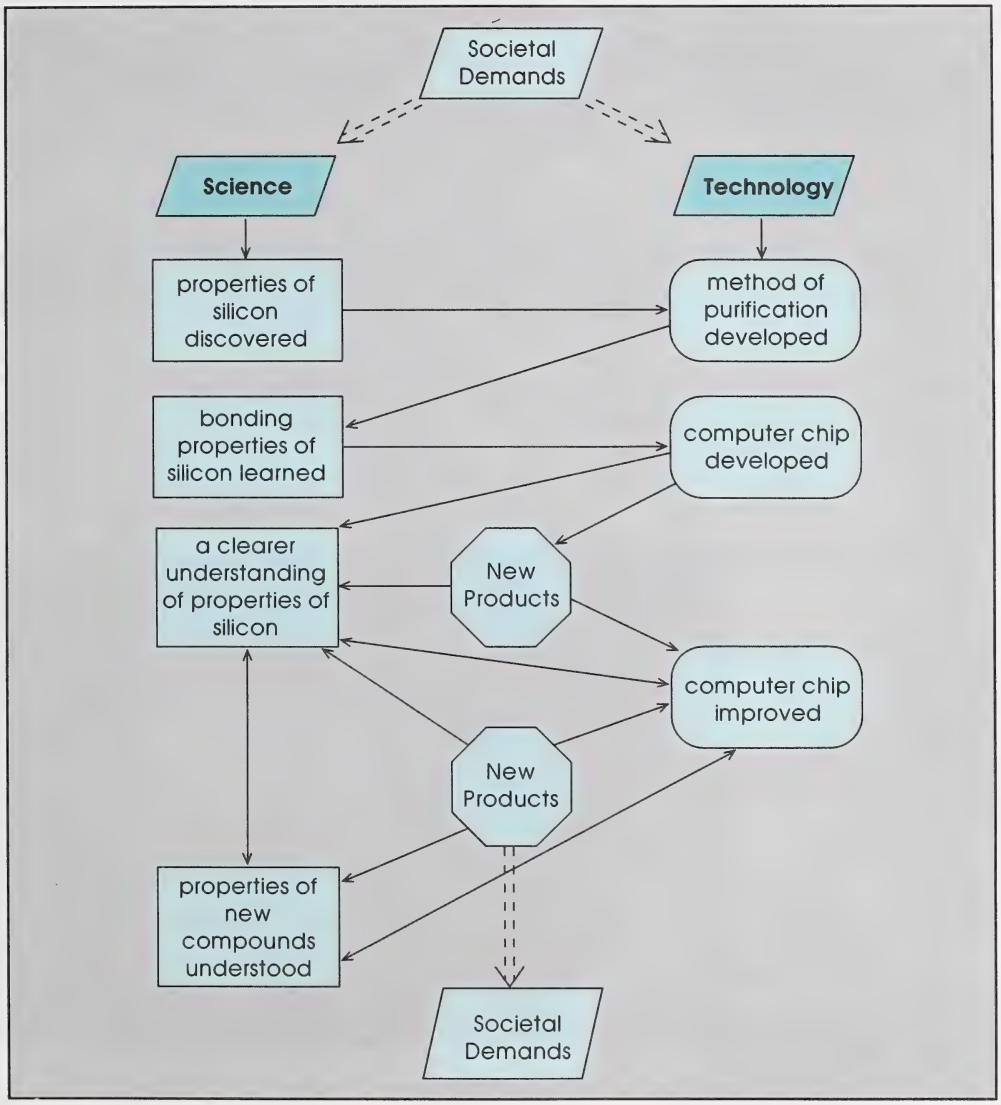


FIGURE 5.18: Interdependence of Science and Technology

7. What special property of the metalloid, silicon, makes it so useful for computer use?

8. How does technology help to advance a scientist's understanding of the nature of bonding?

9. All of the following objects can be made using either ceramic or composites. Decide whether the listed objects would be best made of a composite or a ceramic.

   a. tennis racquets, skis, bicycles
   b. nose cone of the space shuttle
   c. engine parts of an automobile
   d. body part of an automobile
   e. tires
   f. ovens
   g. protective sports equipment

Check your answers by turning to the Appendix, Section 4: Activity 3.

In this activity, you learned how computers and other analytical instruments are used by scientists to help them understand more about bonding and in developing new compounds. New discoveries often lead to the development of a new technology. In turn the new technology helps the scientists. For example, crystals of greater purity must now be grown for use in microcircuits, but gravity interferes. These crystals must be built in space. How will this technology help science and affect you?

NASA

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

Some important points to remember about intermolecular forces are the following:

- They are between molecules.
- They are weaker than intramolecular forces.
- They are mainly responsible for the physical properties of molecular compounds.

When discussing bond energies, some important concepts are the following:

- Exothermic means bonds are formed and energy is lost.
- Endothermic means bonds are broken and energy is gained.

1. For each of the following statements, decide whether the net change is exothermic or endothermic and whether the bonding involved is mainly intermolecular or intramolecular.

   a. popping a balloon

   b. putting hot sodium in chlorine gas to produce a vigorous reaction and light

   c. making liquid ammonia from gaseous ammonia

   d. digesting food

   e. growing of a plant in the sunlight

   f. crushing a sugar cube

2. When you break a bond in a molecule, is the final energy of the product higher or lower?

3. Predict what will happen to the melting point of a molecule if its polarity increases.

4. Describe a test for determining whether or not a molecule is polar.

Another important thing to remember from this unit is that technology and science help each other develop. At the centre of this development is the computer. Examine Figure 5.19. Use Figure 5.19 for help in answering the following question.

5. Write down the items from the following list that would not usually involve the use of computers at some point in their development.

   - automobiles
   - CD player
   - roller blades
   - art
   - sports
   - telephone
   - sleeping
   - banking
   - telephone/VCR

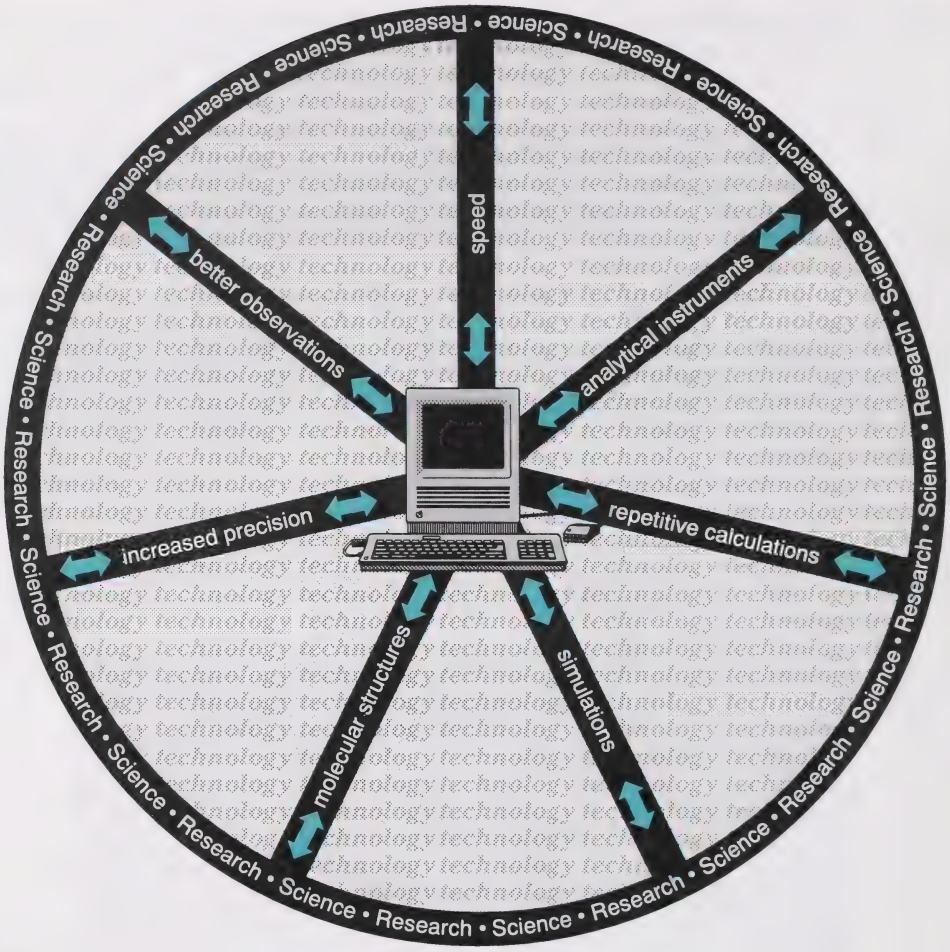

Science • Research • Science • Research • Science • Research • Science • Research • Science • Research • Science • Research • Science • Research • Science • Research • Science • Research • Science • Research
speed
analytical instruments
repetitive calculations
simulations
molecular structures
increased precision
better observations

FIGURE 5.19: The Use of the Computer in Science

Science and technology also help people cope with more serious problems such as in the area of health care.

6. Because of the special bonding properties of some perfluorocarbons (carbon and fluorine compounds), this class of compound is being examined as a possible substitute for red blood cells.

   The following table lists some science and society and technology steps that deal with the development of artificial blood. The steps within each part are in the correct order. Create a sequence on your page using the numbers and letters from each part so that the Technology steps fit in the correct order with the Science and Society steps.

   Example: 1 → 2 → a → b → etc. (The example is not the correct order.)

Part A: Science and Society	Part B: Technology
1. Blood is discovered. (Science)	a. The microscope is developed. It is able to see the major components of blood. (Technology)
2. After identifying the major components of blood, it is discovered that red blood cells carry oxygen. (Science)	
3. For various reasons, the demand for a blood substitute increases. The main function of this substitute is to replace the job of red blood cells. (Society)	b. As the search for a blood substitute begins, new instruments are being developed that help determine how a red blood cell works. (Technology)
4. The search for a blood substitute begins. (Science)	
5. The knowledge of the chemical properties of the red blood cell help in the search for a new chemical substitute. (Science)	c. As the ability to detect molecular structures increases, knowledge of the properties of the new perfluorocarbons increases, but not enough to be tested on animals. (Technology)
6. Special perfluorocarbons are developed that are able to bond to oxygen and carbon dioxide in a similar manner, but more efficiently than red blood cells. (Science)	
7. Finally, a compound is developed that works in animals. (Science)	d. Analytical instruments continue to help analyse the newest perfluorocarbon to help eliminate side effects in humans. (Technology and Science)
8. There are side effects when tested on humans, and health officials do not approve it. (Science and Society)	

Check your answers by turning to the Appendix, Section 4: Extra Help.

Enrichment

Do **one** of the following activities.

1. More and more science is being used to fight crime. One of the latest uses of technology that relies on intermolecular forces is DNA fingerprinting. A person's DNA fingerprint is part of him or her. It cannot be forged. All that is needed are a few body cells left at a crime scene and a few cells taken from a suspect for comparison. This is very useful evidence at crime trials such as rape cases.

   Using the resources available to you describe how DNA fingerprinting is done. Relate this to the bonding concepts you have learned in this section.

2. As athletes become more and more pressured to win at any cost, it becomes a greater and greater temptation to use drugs for enhancing their performance. But at top competitive levels all medal winners are automatically tested for drugs. Use the resources available to you to describe how drug testing is done, and how masking agents are used to try to cover up drug use. Relate this to the principles of bonding you have learned. You may even want to visit a drug testing facility to see for yourself how testing is done.

3. Think of your favourite perfume or aftershave. Did you ever wonder how it was made? Why are colognes or toilet waters cheaper? Why don't they last as long as perfume? Use the resources available to you for answering these questions, making sure you relate the answers to the principles of bonding you have learned.

Check your answers by turning to the Appendix, Section 4: Enrichment.

Conclusion

In this section, you learned about the basic energy changes that occur when bonds are broken or made. You discovered that some of the energy changes can be relatively great if intramolecular bonds are broken or formed, while the energy changes are much smaller if intermolecular bonds are broken or formed. Polarity and size of molecules are related to the strengths of intermolecular forces as well. Finally, you examined the way science and technology intermix as they allow scientists to make new discoveries. Some of the newer discoveries were discussed to see how they influence your life.

25

Section 4 Assignment: Bond Strength and Applications

Review the Evaluation information found in the introductory pages of this module.

It is important to number and clearly identify each page with the following information at the top:

Chemistry 20 – Module 5 Section 4 Assignment Page # Name and ID #

Be sure to write legibly. Leave a wide left margin and number all of your pages.

1. To survive, your body needs sugars and oxygen. Explain how the forces between sugar molecules $(C_6H_{12}O_6)$ are similar to the forces holding oxygen atoms together inside oxygen molecules. **(1 mark)**

2. When frozen orange juice is left at room temperature, it melts. When molten steel is left at room temperature, it solidifies.

   a. Which of these two examples is endothermic? **(1 mark)**

   b. Explain why it is an endothermic process. **(2 marks)**

   c. Explain why the other example is exothermic. **(2 marks)**

3. You notice steam condensing on a cold pipe: $H_2O_{(g)} \rightarrow H_2O_{(l)}$

   a. When the steam condenses, are bonds broken or formed? **(1 mark)**

   b. Are intramolecular or intermolecular forces involved in this change and why? **(1 mark)**

   c. Is energy gained or released in this process? **(1 mark)**

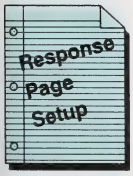
4. a. Rank the following examples from the one that contains the strongest intermolecular forces to the one that contains the weakest. **(1 mark)**

   - Water (ice) melts at 0°C.
   - Rubbing alcohol melts at –89°C.
   - Glycerol melts at 20°C.

   b. Explain how you arrived at your decision. **(2 marks)**

5. Choose the appropriate terms from the following list to complete the substance column in the following chart. **(3 marks)**

   - ionic solid
   - precious metal
   - intermolecular forces
   - composites
   - polar molecule
   - semi-conductor
   - ceramic
   - galvanization



On your response page, list each substance letter (a, b, c) followed by the correct term.

Substance	Property	Example
a. _____	• able to withstand extremely high temperatures • very hard	• on nose cone of space shuttle
b. _____	• allow objects to stick together • give rise to high melting and boiling points of molecular compounds	• in plastic food wrap
c. _____	• flexible and light • very strong	• in a lot of sports equipment

6. State three ways the intermolecular forces in a methanol (CH_3OH) sample differ from the intramolecular forces in a methane (CH_4) molecule. **(3 marks)**

7. The computer and various analytical instruments are being used more and more in helping scientists learn about existing substances, or even in developing new substances. One area is in the development of new ceramics.

   a. In one-third to one-half page, explain four ways a computer could be used specifically to help a person who is developing a new ceramic. **(4 marks)**

   b. State two ways in which the analytical instruments have helped scientists develop such materials as these new ceramics. **(2 marks)**

   c. Explain what would happen to scientific research if technology did not continue to develop. **(1 mark)**

MODULE SUMMARY

Have you now learned what holds materials together? Do you feel confident in explaining how salt is different from water?

In this module, you learned how the periodic table can be used to predict basic bonding concepts necessary for a better understanding of ionic and molecular compounds. This understanding was developed in the last section to include a comparison of bond strengths and how scientists use their knowledge of bonds to help develop technology as it relates to society.

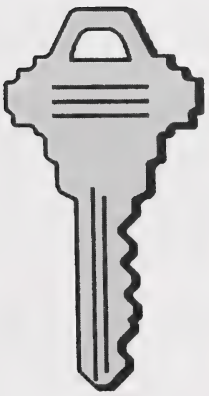
To ensure that all of your work has been completed in a satisfactory manner, check off the items in the following list:

- ❑ Section 1 Assignment has been completed.
- ❑ Section 2 Assignment has been completed.
- ❑ Section 3 Assignment has been completed.
- ❑ Section 4 Assignment has been completed.
- ❑ Your responses are organized and neat, with room for teacher comments.
- ❑ All your response pages are numbered consecutively and identified with this heading.

  Chemistry 20 – Module 5 Section # Assignment Page # Name and ID #

Submit **only** your **assignment response pages** for evaluation.

Appendix



Glossary

Activities

Extra Help

Enrichment

Glossary

anion: a negative ion

Bohr model: a representation that shows small, negatively charged electrons circling a positively-charged nucleus in discrete energy levels similar to the way the planets orbit the sun

bonding capacity: the number of bonds an atom will make to complete its octet

bonding electron: an unpaired electron that occupies a valence orbital and that forms bonds in an atom

cathodic protection: attaching a more reactive metal to a less reactive one to protect the less reactive metal from corrosion

cation: a positive ion

ceramic: a hard, clay-based material that resists very high temperatures

chromatography: separates one kind of molecule from another usually based on molecular polarity

complete octet: having a completely filled valence shell, similar to the noble gases

composite: material made by imbedding or mixing fibres into a plastic or resin base

corrosion: the loss of electrons by a metal when it reacts with moist air

covalent bond: a bond that involves two atoms within the same molecule sharing electrons

crystal lattice: the regular arrangement of cations and anions in an ionic compound

crystallography: method used to determine the crystal structure of a compound

diatomic: having two atoms in each molecule

electronegativity: a relative measure of the desire of an atom to attract or gain electrons when bonding

endothermic: having energy absorbed

exothermic: having energy given off

family: a vertical column on the periodic table

formula unit: the smallest ratio of ions that has a net charge of zero and exists in the same ratio of ions as found in the crystal

friction: force of attraction involved when two touching surfaces slide past each other

galvanization: the coating of metals to prevent corrosion

group: a vertical column on the periodic table

half-reaction: an equation that represents half of an overall process – either oxidation or reduction

ionic bond: a bond formed when the more electronegative of two atoms takes the electron from the less electronegative atom
The difference results in a cation and an anion being attracted to each other. The cation is formed from a metal atom, while the anion is formed from a nonmetal atom.

ionic compound: the product formed by the reaction of a metal and a nonmetal resulting in a series of cations and anions arranged in a regular pattern in a crystal lattice

intermolecular force: the weak forces of attraction between molecules

intramolecular force: the forces of attraction between atoms within a molecule

law of conservation of matter: scientific law that states matter can neither be created nor destroyed

Lewis model: a way to represent the way molecules or atoms join together by using dots to represent valence electrons; by pairing dots, bonds are formed until each atom in the molecule gains a complete octet

light spectroscopy: using various types of light energy to help in chemical analysis

London dispersion forces: a particular type of intermolecular force

lone pair: two electrons that occupy the same valence orbital in an atom
(They cannot form any bonds as discussed in this course.)

mass spectrometer: an analytical instrument, one function of which is to determine the molar mass of a compound

metalloids: the set of elements from Groups 13 to 17 that have both metallic and nonmetallic properties

molecular compound: the compound formed from the reaction of two or more nonmetals

molecular formula: the formula that shows how many of each kind of atom are present in one molecule of the substance

non-polar covalent bond: a bond formed when electrons are evenly shared between two atoms within a molecule
The electrons spend equal time around each atom because the electronegativities of the atoms are the same.

non-polar molecule: a molecule in which the electron density on the outer edges of the molecule is evenly distributed

octet rule: when atoms react, they will gain or lose electrons in order to obtain the same number of electrons in their valence shells as a noble gas

orbital: a region of space around an atom where an electron will most likely be found

oxidation: loss of electrons

oxide: the product of a reaction between a metal and oxygen

periodicity: regularly repeating properties of the elements as the atomic number increases

polar covalent bond: a bond formed when electrons are unevenly shared between two atoms within a molecule
The electrons spend more time around the more electronegative atom.

polar molecule: a molecule in which the electron density on the outer edges of the molecule is unevenly distributed, resulting in parts of the molecule being slightly positive and other parts being slightly negative

polyunsaturated: having many multiple (double, triple) carbon-carbon bonds

reduction: gain of electrons

saturated: having only single carbon-carbon bonds

scanning tunnelling microscope: analytical instrument able to detect individual atoms in certain materials

structural diagram: a diagram that indicates the way atoms are bonded together in a molecular compound by using lines to represent the bonds

symmetrical: having balanced proportions on all sides

valence electron: the electrons in the outermost energy level of an atom

valence orbital: the outermost (highest) energy orbital in an atom; the orbital where the electrons are furthest from the nucleus

valence shell: a synonym for the four valence or outer orbitals of an element

Suggested Answers

Section 1: Activity 1

1. The letters on the periodic table represent these areas:

   - **A** noble gases
   - **B** alkali metals
   - **C** representative elements
   - **D** transition metals
   - **E** halogens

2. Alkali metals are soft, silver-coloured metals that do not naturally exist because of their extreme reactivity. When placed in water, they react violently to form basic solutions. They also react vigorously with members of the halogen family to form white salts.

3. A horizontal row on the periodic table is called a **period**.

4. a. The elements within the same family form compounds that have similar chemical formulas – the ratios between atoms are the same.

   b. The chemical formula would be CsF. This is because cesium is in Group 1 and fluorine is in Group 17 of the periodic table. All of the examples in Group 1 are joined to just one chlorine, which is in Group 17 like fluorine. Therefore, fluorine should behave the same way as chlorine when it attaches to a Group 1 element.

5. Elements are arranged in chemical families because they have similar chemical properties.

6. An activity series is a pattern of reactivity for specified elements. Each element in the group is reacted in an identical format. Elements are then arranged according to the degree to which they react.

7. Each metal will be placed in a small quantity of dilute hydrochloric acid. Observations will be made to see how rapidly each metal reacts with the acid.

8. **Note:** The suggested amounts are for use with test tubes. Minor changes in amounts may be needed if beakers or microtrays are used.

   Your materials list should include the following:

   - small pieces of the following materials
     - calcium, Ca
     - copper, Cu
     - iron, Fe
     - lead, Pb
     - magnesium, Mg
     - zinc, Zn
   - 20 mL of 1.0 mol/L $HCl_{(aq)}$
   - plastic tweezers
   - steel wool
   - safety glasses
   - Depending on how you plan to carry out your investigation, the following glassware could be listed:
     - 6 test tubes and one test tube rack, **or**,
     - (6) 50 mL beakers and a watch glass, **or**,
     - 1 microtray and cover

9. Before proceeding to carry out your investigation, make sure your procedure is similar to the following:

   - Fill each of the six test tubes not more than 1/4 full of 0.10 mol/L $HCl_{(aq)}$. (The extra height of the test tube walls will prevent the acid from spitting out of the test tube as it reacts.) Place the test tubes into the test tube rack.
   - Using the tweezers, place the calcium carefully into the first test tube. Make sure the calcium is dry. DO NOT TOUCH THE CALCIUM WITH YOUR FINGERS! Because of the oxide coating, it may take a few seconds before the calcium begins to react.
   - Record the observations in a data table.
   - Polish each of the other metals with some steel wool, until the metal is shiny. This is to remove the oxide coating that forms on many metals.
   - Using tweezers, carefully place the copper in test tube 2, the iron in test tube 3, the lead in test tube 4, the magnesium in test tube 5, and the zinc in test tube 6.
   - Make observations and record them in your data table.
   - Once you have completed your observations, turn on the cold water tap. With the water running, carefully pour the acid down the sink. Check to see if a laboratory instructor can re-use any of your unreacted metal. If not, you may discard any unreacted metal in a trash container.
   - Wash the rest of your materials and return them to their proper storage area.

10. After performing the investigation, the data table should be similar to the one provided here.

Metal Used	Observations
calcium	Very vigorous bubbling occurred after about a half-second delay. The calcium disappeared.
copper	A very slight discolouration of the metal was seen after one hour.
iron	A discolouring of the iron was observed after half an hour. The metal above the solution looked a little rusty as well.
lead	After five minutes, a few bubbles were observed. The lead had become darker in colour.
magnesium	Vigorous bubbling occurred. The magnesium began to disappear.
zinc	Slight bubbling was observed.

11. Each metal will be placed in a small quantity of dilute hydrochloric acid. Observations will be made to see how rapidly each metal reacts with the acid.

12. Refer to the answer for question 8 in this activity, Section 1, Activity 1.

13. Refer to the answer for question 9 in this activity, Section 1, Activity 1.

14. Refer to the answer for question 10 in this activity, Section 1, Activity 1.

15. a. The order of reactivity (the activity series) should be as follows from most reactive to least reactive: calcium, magnesium, zinc, lead, iron, copper.

    b. Possible discrepancies that you may observe are as follows:

    - One of the metals did not react. Possible reasons could be the following:
      - The oxide coating on the metal was not properly removed.
      - The acid used was too dilute. This would affect the degree of reactivity for all the metals.
      - The metal was not left in the acid long enough, so no observable change was seen.
    - Another discrepancy could be that bubbles were observed after a period of time when there shouldn't have been any. A possible reason could be that air in the acid simply collected on the surface of the metals making it appear that the metal was reacting to produce gas.

16. Based on the investigation, a very general statement would be that as you proceed from left to right across the periodic table, the reactivity of metals decreases until near the end of the transition metals. Then the reactivity begins to very slowly increase again.

17. a. The basic properties of the oxides decrease and the acidic properties increase as you move from left to right across the third period. This would suggest that the alkali metals would react most vigorously as they produce oxides with basic properties, while the halogens would react the most vigorously as they produce oxides with acidic properties.

    b. Extrapolating the data, you could conclude that the reactivity of the elements decreases as you proceed from sodium to aluminum and silicon. Then the reactivity increases again. The properties of the compounds on either end of the periodic table will be more extreme than those near the middle. Therefore, the trends are similar to those found in Investigation 8.1.

18. a. When a metal reacts with a nonmetal, an ionic substance is formed.

    b. An ionic substance would form a nonconducting, crystalline solid with a high melting point. It would not conduct electricity in its solid form but would conduct electricity in aqueous solution or in the liquid state. A molecular substance would not conduct electricity. In general it would also have a lower melting point than an ionic solid. It could therefore exist as a solid, liquid, or a gas in its pure form. Thus, to distinguish between the two substances, you could check the conductivity of the liquid or solution form of each or check each one's melting point (not as reliable).

19. a. The two most reactive families are the alkali metals and the halogens.

    b. The two least reactive regions of the periodic table are the noble gases and the elements near gold and platinum in the central region of the table.

Section 1: Activity 2

1. Electrons are either shared as in covalent bonding or transferred to make ions as in ionic bonding.

2. a. If a particular element has five valence electrons, then its group number is **15**.

   b. The maximum number of valence electrons a representative element can have is **8**.

3. The number of valence electrons that each element will have is given here:

   a. 2 c. 6 e. 3 g. 8 i. 2

   b. 4 d. 1 f. 5 h. 7

4. a. A valence orbital is the outer or highest energy orbital of an atom.

   b. Each representative element has four valence orbitals.

5. Each orbital can have a maximum of two electrons.

6. Electrons half fill the empty valence orbitals before pairing because electron repulsion causes them to be as far apart as possible.

7. Single valence electrons are called **bonding electrons** while paired valence electrons are called **lone pairs**.

8. The diagram should be labelled as follows:

   a. lone pair c. element symbol e. valence orbitals

   b. valence orbitals d. bonding electron

9.

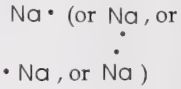
Element	Number of Valence Electrons	Electron Dot Diagram	Number of Bonding Electrons	Number of Lone Pairs
calcium	2	$\cdot Ca \cdot$	2	0
germanium	4	$\cdot \dot{Ge} \cdot$	4	0
potassium	1	$K \cdot$	1	0
sulphur	6	$\cdot \ddot{S} :$	2	2
nitrogen	5	$\cdot \ddot{N} \cdot$	3	1
aluminum	3	$\cdot Al \cdot$	3	0
neon	8	$: \ddot{Ne} :$	0	4
fluorine	7	$\cdot \ddot{F} :$	1	3
helium	2	$He :$	0	1

10. a. The diagram is incorrect because the electrons are paired. Electrons must fill all the empty orbitals before they begin to pair up. The correct representation of carbon is as follows: $\cdot \dot{C} \cdot$

b. The diagram is incorrect because there are more than two valence electrons in one of the orbitals. The electrons should half-fill all orbitals before they are paired. Drawn correctly, phosphorus would look like this:

c. The diagram of boron is incorrect because the drawing suggests only three valence orbitals. For the representative elements, there should be four valence orbitals. Therefore it should look like the following where one orbital is left vacant, but its position is still there.

d. The diagram is incorrect because sodium is shown with eleven electrons in its valence shell. This violates the octet rule which states that an atom can only have a maximum of eight electrons in a valence orbital. Sodium only has one valence electron because it is a Group 1 element. The drawing also suggests that sodium has six valence orbitals rather than four. Redrawn, the correct representation of sodium would look like this:



The electron can be shown in any of the four orbital positions to be correct.

e. The diagram is incorrect because the element symbol is incorrect. Redrawn, the correct representation of potassium would look like this:

f. The diagram is incorrect because it suggests that sulphur has six valence orbitals. Representative elements have only four valence orbitals. The diagram should be as follows:

11. The four sides of the atom indicate that there can be a maximum of four valence orbitals for a representative element. Drawing unpaired electrons around the atoms until all the valence orbitals are filled shows that electrons will occupy empty valence orbitals before pairing up. Pairing the electrons in four groups of two illustrates the octet rule and the fact that any given orbital can hold no more than two electrons.

12. a. The element that is most electronegative is **fluorine**.

b. The element that is least electronegative is **francium**.

13. Noble gases have no electronegativities because they have a complete octet. With a full valence shell, they have no desire to gain electrons nor a desire to lose electrons.

14. Metals generally have low electronegativities because they have few valence electrons which creates a weaker attraction to the nucleus. While they still desire electrons, they easily lose an electron to an element that has a greater desire for electrons (a higher electronegativity).

Nonmetals have high electronegativities because they have a relatively large number of valence electrons. Thus they have a strong desire to attract the few electrons needed to complete their octet.

15. Elements with high electronegativities attract electrons strongly, while elements with low electronegativities have a weak electron attraction. Because of this weak attraction, they release electrons fairly easily. The combination of the easy release and strong attraction makes for a very reactive situation.

16. The octet rule states that all atoms desire to attain eight valence electrons. The closer the atoms are to attaining this number, the greater the desire to finish filling the orbital. Electronegativity is a measure of the desire for a complete octet.

Section 1: Activity 3

1. Your first inclination is probably to group the two gemstones (diamond and emerald) together and the two granular substances (table salt and sand) together. The correct pairing, however, is diamond and sand and table salt and emerald.

2. Helium does not bond with other atoms at all, but hydrogen can bond with another hydrogen atom or other types of atoms.

3. a. When there is a balance between attractive forces (electrons ⊖ to ⊕ in the nucleus) and repulsive forces (⊕ to ⊕ or ⊖ to ⊖), hydrogen atoms can get close enough together to overlap and share one pair of electrons.

   b. The type of bond where electrons are shared is called a covalent bond.

4. Helium atoms will not bond because they cannot get close enough together to share electrons before repulsive forces are stronger than attractive forces. Also, the helium atoms already have as many valence electrons as possible and have little desire to gain or lose electrons.

5. The two factors that determine the strength of forces are the distance between the forces and the size of the charges.

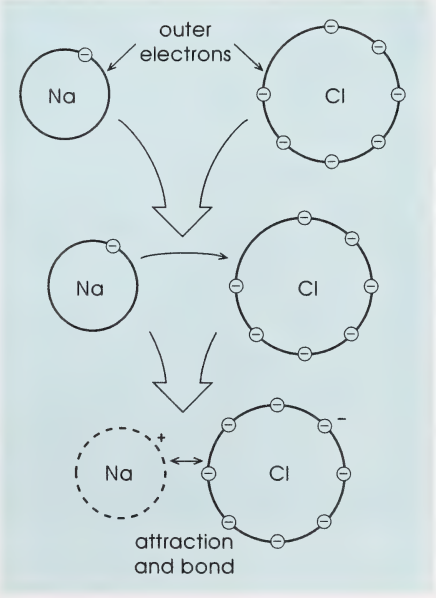
6. a. The outer 3s electron (the valence electron) is the key to bonding.

   b. The two reasons for sodium's outer electron being loosely held are:

      - The electron is far from the nucleus, so the force of attraction is weak.
      - There are many electrons between the outer electron and the nucleus, which diminishes the attraction (the inner electrons shield the outer electrons from attraction to the nucleus).

7. a. Sodium has a weak attraction for its one outer electron; chlorine has a strong attraction for its seven outer electrons. When a sodium atom and a chlorine atom come close together, chlorine attracts sodium's outer electron and sodium lets it go. This creates a positive sodium ion and a negative chloride ion. A strong attraction then develops between the oppositely-charged ions and a bond forms.

   b. This type of bond is called an ionic bond.



8. Possible bond types and a description of each are as follows:

   - A covalent bond involves two atoms sharing electrons equally.
   - An ionic bond is formed by the transfer of an electron from a less electronegative atom to a more electronegative atom.
   - The third type of bond is something in between covalent and ionic.

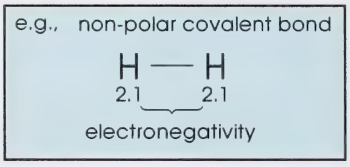
9. Noble gases exist in a generally unreactive state because they have a completed outer energy level of eight electrons. That is, their octet is complete. With a complete octet, the repulsive forces between the atoms are stronger than the attractive forces.

10. a. When an atom forms a bond, its valence or outer shell becomes filled. It has a complete octet of electrons.

    b. This is a stable arrangement because both atoms involved in the bonding obtain a complete octet of electrons.

11. When atoms achieve an octet of electrons, their electron arrangements become similar to the nearest (nearest in atomic number) noble gas.

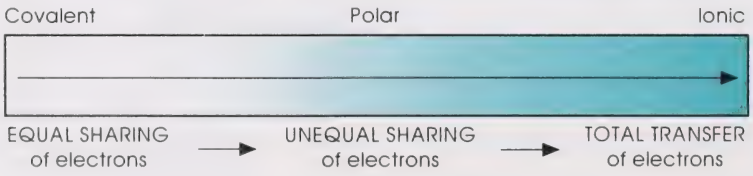
12. a. A non-polar covalent bond is one in which electrons are evenly shared between atoms. The atoms have the same electronegativities;



    b. An ionic bond is one that forms between a metal and nonmetal. There is a large difference in electronegativity between the two atoms.

    c. A polar covalent bond is one in which electrons are unevenly shared. There is a slight difference in electronegativity.

13. Your sketch should show a continuum of some sort with covalent bonding on one side, ionic bonding on the other, and polar bonding in between. An example is shown here:



14.

Type of Covalent Bond	Similarities	Differences
single	• All bonds result from shared electrons. • Bonds are created by each atom donating one electron to make one bond. • Each bond involves two electrons.	• Only two electrons are used in total.
double		• Bonds use four electrons in total. • Bonds are like two single bonds between two atoms.
triple		• Bonds use six electrons in total. • Bonds are like three single bonds between two atoms.

15. The octet rule determines the number of bonds an atom will make to achieve an octet of electrons (eight electrons).

16. Electronegativity determines the type of bond that will form between two atoms, that is, whether it's non-polar covalent, polar covalent, or ionic.

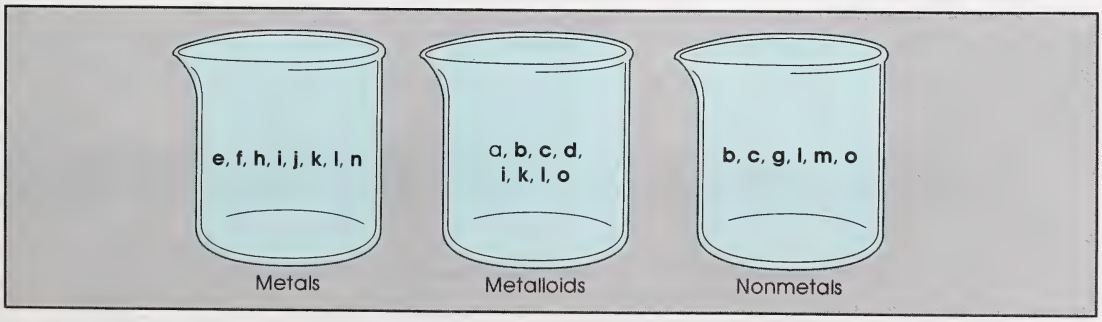
17. The electrons are more attracted to and spend more time around the atom with the greater electronegativity.

18. Even though $CaCO_3$, $CuSO_4$, and KNO_3 contain more than one nonmetal, these nonmetals are grouped into complex ions that have a net negative charge just like a simple nonmetal. Therefore, complex ions attract to metal ions and form ionic compounds the same as metal and nonmetal simple ions.

19.

Atoms Bonding	Type of Bond Formed	Description of Bonding Electrons
S and Mg	ionic	transferred to S
N and Cl	ionic	transferred to Fe
Fe and O	polar covalent	closer to O
C and S	non-polar covalent	shared equally
H and O	non-polar covalent	shared equally
P and F	non-polar covalent	shared equally
F and F	polar covalent	closer to F

20.



Note: Some properties may overlap more than shown. The answers given are usually for the majority of elements in each class.

21. a. Metalloids form covalent bonds.

b. Covalent bonds are strong, but they only allow electron motion between the atoms in one direction (directional bond). Other types of bonds allow electron motion in any direction. This explains metalloids' hardness, high melting points, and rigid three-dimensional shapes. Because all their valence electrons are involved in bonding, metalloids are not good conductors of electricity.

22.

Substance	Type of Bond (non-polar covalent/polar convalent/ionic)	Molecular or Ionic?	Use or Description
water	polar covalent	molecular	– for drinking – 80% of your body's mass
table salt (sodium chloride)	ionic	**ionic**	– found in saline solution – seasons food
coal	**non-polar covalent**	**molecular**	– burned to produce electricity in many places
rust	**ionic**	**ionic**	**– causes billions of dollars of damage each year**
gasoline (octane)	**non-polar covalent**	**molecular**	– fuel burned in most automobile engines
nitrogen dioxide	**slightly polar covalent**	**molecular**	– reddish-coloured smog
bleach	**ionic**	**ionic**	– cleaning agent that conducts electricity
nitrogen	**non-polar covalent**	**molecular**	– main constituent of air
sugar	**non-polar covalent and polar covalent**	**molecular**	**– used as fuel for your body**
DNA	**non-polar covalent and polar covalent**	**molecular**	**– the blueprint (genetic material) of your body**
silicon	**non-polar covalent**	**molecular**	– primary ingredient of computer chips
baking powder	**ionic**	**ionic**	**– used in baking**

Section 1: Follow-up Activities

Extra Help

1.

Bond Type	Electronegativity Difference	Type of Compound Formed	Elements Involved	Example
non-polar covalent	zero	nonmetal with nonmetal	molecular	**CH_4**
polar covalent	small to medium	**nonmetal with nonmetal**	**molecular**	**H_2O**
ionic	large	**metal with nonmetal**	ionic	**$CaCl_2$**

Note: Metalloids usually combine with other elements to form **covalent** bonds.

2. a.

Element	cesium	aluminum	chlorine	silicon	argon
Degree of Reactivity	high	medium	high	low	very low (almost none)
Reason for Degree of Reactivity	It is easy to lose one valence electron and become stable like a noble gas.	It must lose three valence electrons to get a complete octet. Three are harder to lose than one.	It only needs to gain one more valence electron to get a complete octet.	It must lose or gain four electrons. This is very difficult to do.	It has a complete octet of eight valence electrons.
Electronegativity	0.7 – low attraction	1.5 – medium attraction	3.0 – high attraction	1.8 – some attraction	none – noble gas
Reason for Size of Electronegativity Value	It has one valence electron so is very far from a complete octet.	It has three valence electrons so is closer to a complete octet.	With seven valence electrons, it is very close to a complete octet.	It has four valence electrons and is half-way to a complete octet.	It has a complete octet.

b. When the electronegativity of an element is high or low, which means the element is closer to the left or right sides of the periodic table, the element's reactivity is high. When the electronegativity of an element is mid-range, the degree of reactivity is low and the element is usually closer to the middle of the periodic table.

The exception to the last statement is the noble gases.

Remember, these statements are generalizations only and can have exceptions.

3. An atom such as magnesium with two valence electrons has a high reactivity because it is relatively easy for the atom to lose its electrons and become stable like a noble gas. The atom has a low electronegativity because the valence electrons are far from the nucleus and are shielded by inner electrons – this decreases the attraction of the valence electrons for the nucleus. Also, it would be very hard for magnesium to gain six electrons to complete its octet. Therefore the atom has a low desire to gain electrons.

4. a. **nitogen**

c. **francium**

b. **krypton**

d. **carbon**

Enrichment

1. There are many possible answers, but here is one example.

Germanium was used in the first transistor in the late 1950s because it was a semiconductor, one of the properties of a metalloid. However, germanium has a relatively low melting point, so when the transistor heated up, the germanium melted.

It was replaced with silicon, which is also a metalloid in the same family except with a higher melting point. This is due to its stronger covalent bonds. To change the properties of silicon slightly and make it a much better semiconductor, other elements from Group 13 or 15 are added. These include such elements as boron, indium, phosphorus, and antimony – mostly metalloids. This process is called doping.

Doping affects the degree to which the electrons are held to the nucleus of the silicon atoms. Different amounts of doping will create transistors with different semiconductive properties.

Today, researchers are studying ways to use crystals such as rubies as storage devices. Because rubies are held together by strong covalent bonds, the atoms will not move very much in the regular crystal structure. Researchers are trying to discover if they can use this atomic arrangement to store large volumes of information. This would create a whole new class of even smaller, more powerful, and faster computers, because the distance the electricity (electrons) would have to travel is much less.

2. All metals used in the alloys for replacement parts of the human body are transition metals. The metals mentioned in the question are also all in the fourth period of the periodic table.

   The three special properties that make them useful for use in the human body are their hardness, their lower atomic mass, and their low reactivity.

   These metals are hard because the electrons are held close to the nucleus of the atom, creating a more rigid bond than most other metals have. This is important because the metals used in the body will undergo a great deal of stress in their day-to-day use.

   Because these elements also have lower atomic masses, they are not especially heavy when compared to other elements such as platinum. This makes it easier for the muscles to move them and makes it less tiring for the person.

   Most importantly, these elements must have a low reactivity so they do not become pitted. They do not contaminate the body itself with the ions of these metals. This would create a much worse problem than using an artificial limb.

3. There are many possible answers, but your answer should address the following considerations.

   - What are other uses of manganese, platinium, and chromium?
   - What other countries have a supply of these metals?
   - What is the political and economic situations of those countries?
   - What similar substitutes are potentially available?
   - Which is the greater good?

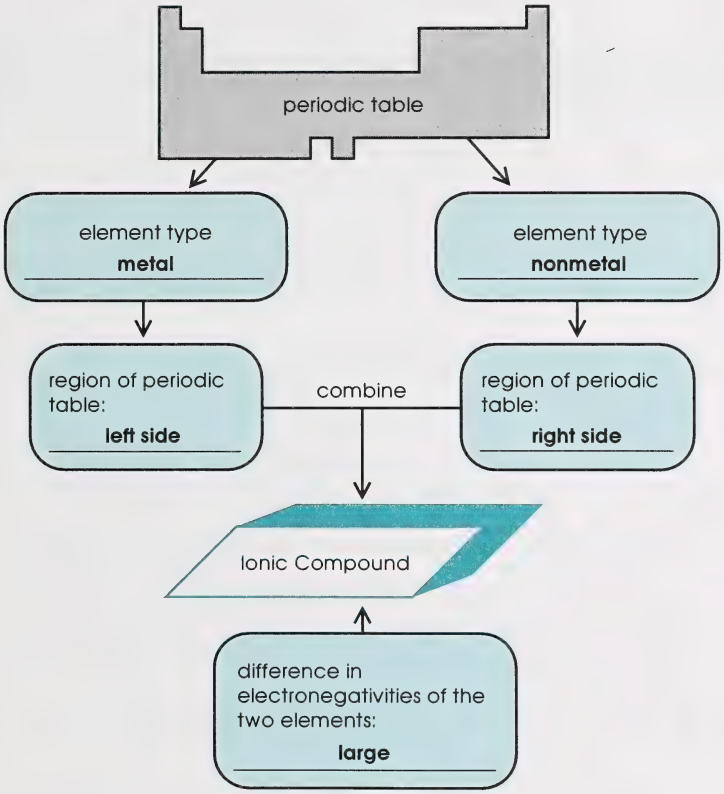
     – Deal with the country in light of potential injustices.

     – Do not deal with the country and have no supplies, or cause the world market to rise because of increased demand on the smaller suppliers. If this means it will cost Canada more, what will be the effect on the Canadian people?

   Your final decision should also be based on ethical grounds (What is right?), and taking into account what is environmentally (What will happen to the environment?) and socially just (What about the people?). It should not be based on purely scientific or political arguments.

Section 2: Activity 1

1.



2. **Textbook question 1:**

a. sodium oxide

b. $CaS_{(s)}$

c. potassium nitrate

d. $FeCl_{3(s)}$

e. mercury(II) oxide

f. calcium sulphate dihydrate

g. $PbO_{2(s)}$

h. $Na_2SO_4 \cdot 10\ H_2O_{(s)}$

i. $Al_2O_{3(s)}$

j. $Ca_3(PO_4)_{2(s)}$

3. **Textbook question 23:**

Some possible examples are the following:

Product Name	Ionic Compound Name	Chemical Formula	Use
table salt	sodium chloride	NaCl	a food seasoning
TSP	tri-sodium phosphate	Na_3PO_4	a mild cleaner
baking soda	sodium bicarbonate	$NaHCO_3$	used in baking
MSG	monosodium glutamate	$NaC_5H_8NO_4$	a food enhancer
chalk	calcium carbonate	$CaCO_3$	used for marking (sewing, construction, blackboards, etc.)
drain cleaner	sodium hydroxide	NaOH	a cleaner
antacid tablet	calcium carbonate and/or magnesium hydroxide	$CaCO_3$ / $Mg(OH)_2$	soothes upset stomach
plaster of paris/ wallboard	calcium sulphate	$CaSO_4$	wallboards, naturally occurring mineral, casts for broken bones
bleach	sodium hypochlorite	NaClO	a cleaner and disinfectant
road salt; sidewalk salt	calcium chloride	$CaCl_2$	melts ice on roads, sidewalks, and driveways
water softener salt	sodium carbonate	Na_2CO_3	softens hard water
fertilizer	potassium nitrate and/or ammonium dihydrogen phosphate	KNO_3 / $NH_4H_2PO_4$	helps plants grow
nitrites	sodium nitrite	$NaNO_2$	helps preserve food
fluorite	calcium fluoride	CaF_2	used as flux, welding solder

4. All of the examples should be circled except *plastic*.

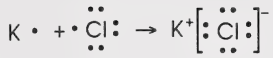
Section 2: Activity 2

1. a. The collision-reaction theory states that atoms of substances such as metals and nonmetals must collide in order to react.

   b. When the atoms of metals and nonmetals collide, electrons are transferred, forming positive and negative ions. Ionic bonds form when the positive and negative ions attract each other.

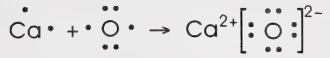
2. Electrons transfer from metals to nonmetals because there is a great difference in the electronegativities of the atoms.

3. a. KCl



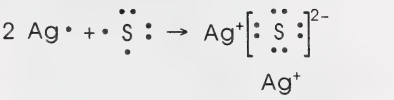
b. LiBr

c. CaO

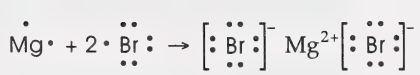


d. FeS

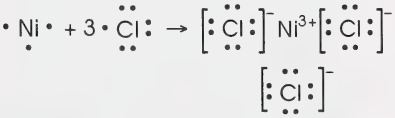
e. Ag_2S



f. $MgBr_2$



g. $NiCl_3$



4. a. When an atom loses electrons to become a cation, **oxidation** has occurred. When an atom gains electrons to become an anion, **reduction** has occurred.

b. Usually, **metals** are oxidized and **nonmetals** are reduced. **Note:** There are exceptions.

5. The total sum of the ion charges must always equal zero in an ionic compound because matter must be conserved and the overall compound must have a neutral charge. When an electron is lost in making a cation, it must go somewhere, which is into making an anion.

6. The only reason electrons are lost from one atom is because there is another atom capable of taking them. In this way both atoms attain a complete octet.

7. a. **strontium:** Strontium would undergo oxidation.

The half-reaction is as follows:

$Sr \rightarrow Sr^{2+} + 2\,e^-$

b. **chlorine:** Chlorine would undergo reduction.

The half-reaction is as follows:

$Cl_2 + 2\,e^- \rightarrow 2\,Cl^-$

c. **sulphur:** Sulphur would undergo reduction.

The half-reaction is as follows:

$S + 2\,e^- \rightarrow S^{2-}$

d. **zinc:** Zinc would undergo oxidation.

The half-reaction is as follows:

$Zn \rightarrow Zn^{2+} + 2\,e^-$

e. **oxygen:** Oxygen would undergo reduction.

The half-reaction is as follows:

$O_2 + 4\,e^- \rightarrow 2\,O^{2-}$

f. **nitrogen:** Nitrogen would undergo reduction.

The half-reaction is as follows:

$N_2 + 6\,e^- \rightarrow 2\,N^{3-}$

8. a.

Reacting elements		beryllium and fluorine
Oxidation half-reaction		$Be \rightarrow Be^{2+} + 2\,e^-$
Reduction half-reaction		$F_2 + 2\,e^- \rightarrow 2\,F^-$
Balanced net reaction		$Be + F_2 \rightarrow BeF_2$
Number of electrons lost (2)	=	Number of electrons gained (2)

b.

Reacting elements		cadmium and nitrogen
Oxidation half-reaction		$3\left(Cd \rightarrow Cd^{2+} + 2\,e^-\right)$
Reduction half-reaction		$N_2 + 6\,e^- \rightarrow 2\,N^{3-}$
Balanced net reaction		$3\,Cd + N_2 \rightarrow Cd_3N_2$
Number of electrons lost (6)	=	Number of electrons gained (6)

c.

Reacting elements		iron and oxygen
Oxidation half-reaction		$4\left(Fe \rightarrow Fe^{3+} + 3\,e^-\right)$
Reduction half-reaction		$3\left(O_2 + 4\,e^- \rightarrow 4\,O^{2-}\right)$
Balanced net reaction		$4\,Fe + 3\,O_2 \rightarrow 2\,Fe_3O_2$
Number of electrons lost (12)	=	Number of electrons gained (12)

9. a. $K + I_2 \rightarrow$

$2\left(K \rightarrow K^+ + e^-\right)$

$I_2 + 2\,e^- \rightarrow 2\,I^-$

$2\,K + I_2 \rightarrow 2\,KI$

b. $Ba + N_2 \rightarrow$

$3\left(Ba \rightarrow Ba^{2+} + 2\,e^-\right)$

$N_2 + 6\,e^- \rightarrow 2\,N^{3-}$

$3\,Ba + N_2 \rightarrow Ba_3N_2$

c. $S + Ni \rightarrow$

$S + 2\,e^- \rightarrow S^{2-}$

$Ni \rightarrow Ni^{2+} + 2\,e^-$

$S + Ni \rightarrow NiS$

d. $Sn + N_2 \rightarrow$

$3\left(Sn \rightarrow Sn^{4+} + 4\,e^-\right)$

$2\left(N_2 + 6\,e^- \rightarrow 2\,N^{3-}\right)$

$3\,Sn + 2\,N_2 \rightarrow Sn_3N_4$

10.

Method	Example
plating one metal with a more reactive one	• chrome plating • galvanized metal • lining on tin cans
attaching a more reactive metal to protect another	• used in salt water to protect motors and ship hulls • protects some metal parts in pipelines
metal produces an oxide coating	• aluminium oxide on aluminium • zinc oxide on zinc
creation of alloys	• stainless steel

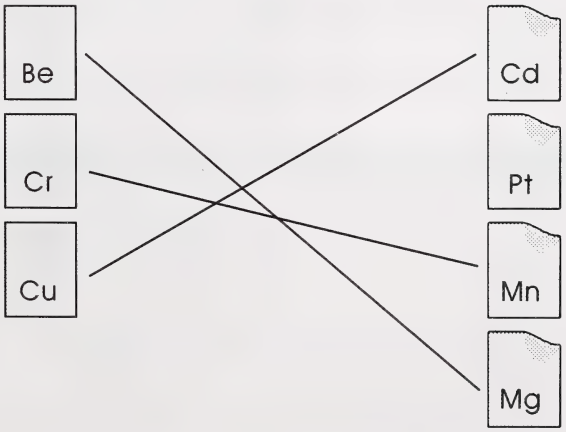
11. The person should use the brass screws because the copper in the brass does not release its electrons as easily as iron. This is because iron has a lower electronegativity than copper. Therefore iron would corrode more easily.

12. Besides being relatively scarce, gold and platinum are precious metals because they are not very reactive. It is very difficult to oxidize them because of their relatively high electronegativities.

13. If zinc did not form a nonreactive coating, it would continue to react until it was totally gone. Then the other metal would begin to oxidize.

14. Rank each element according to its electronegativity. Only an element with a lower electronegativity can be used to protect one with a higher electronegativity. The increasing order (lowest first) is: Mg, Be, Mn, Cr, Cd, Cu, Pt.

Once the ranking is done, the matching is as follows:



Platinum cannot be used because it does not oxidize more easily than any of the metals you want to protect.

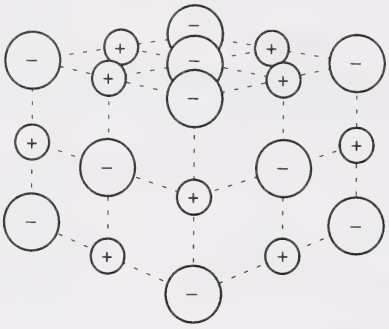
Section 2: Activity 3

1. Covalent bonds are formed from a sharing of two bonding electrons that are simultaneously attracted by the nuclei of both participating atoms. Ionic bonds are formed by the simultaneous attraction of oppositely charged ions to each other.

2. The types of bonds a substance contains usually determines the types of properties the substance will exhibit.

3. NaCl represents the ratio in which the sodium and chloride ions are present in a crystal – a 1:1 ratio. There are actually millions of each type of ion in a crystal, but they are still in a 1:1 ratio.

4. The + and – charges will be arranged as shown here:



5. Because of the strong attraction between ions, the following characteristics or properties result:

   - The ions are held in a fixed position.
   - The crystals are hard; they shatter when dealt a hard blow.
   - The crystals do not conduct electricity or heat.
   - The crystals have high melting points.

6. The ionic compound can either be melted by high temperatures or dissolved to make the ions mobile. The substance would then conduct electricity.

7. The many different shapes of ionic compounds are determined by the sizes and charges of the ions in the compound.

8. a. A crystal lattice is the arrangement of ions in a regular pattern determined by the ions' sizes and charges.

   b. Since strong ionic bonds are formed between the cations and each of the surrounding anions, and vice versa, ionic solids are very rigid with a regular crystal structure. This structure will have a high melting and boiling point.

   c. The following terms describe properties of ionic solids: hard, brittle, solid non-conductor of heat and electricity, high melting and boiling points, regular crystal structure.

9. The formula unit of an ionic compound depends on the relative charges of the ions and the zero sum rule. Since the size and charge of the ions determine the crystal lattice shape, it follows that the formula unit, which involves charges, must determine the crystal shape.

10. The formula unit is NaCl.

11. a. The final shape of the crystal is cubic.

    b. It has the same shape as a salt crystal.

12. The number of chloride ions in the middle of the crystal that surround each sodium ion is **six**, while the number of sodium ions that surround each chloride ion in the crystal is **six**.

13. The crystal model corresponds to its formula unit because the numbers of cations surrounding anions is always the same as the number of anions surrounding cations. The number of cations in the crystal of NaCl, therefore, is always the same as the number of anions.

Section 2: Follow-up Activities

Extra Help

1. The following are the correct formula units of ionic compounds:

   - $CaCl_2$
   - $SrCO_3$
   - Al_2O_3
   - LiF

   Note: Mg_2O_2 and $Fe_3(PO_4)_3$ do not give the simplest whole number ratio of ions, $Ni_2(SO_3)_3$ and Cu_2SO_4 use a less common form of metal ion, and H_2O is not ionic.

2. a. True

   b. False

   c. True

   d. True

   e. True

3. There are many different possible crystal shapes because ions come in many different sizes and charges, which lead to many different formula units.

4. In order to make the number of electrons lost equal to the number of electrons gained, three oxygen atoms are needed and two aluminum atoms are needed.

   $Al^{3+} \times 2 = 6^+$

   $O^{2-} \times 3 = 6^-$

   Total $= 6^+ + 6^- = 0 \leftarrow$ zero sum rule

5.

Ionic Solid	Oxidized Element	Reduced Element
CaO	**Ca**	**O_2**
Na_2S	Na	S
PbO_2	**Pb**	**O_2**
Cu_3N_2	**Cu**	**N_2**
AlF_2	Al	F_2
$FeCl_3$	**Fe**	**Cl_2**

6. a. $4(Fe \rightarrow Fe^{3+} + 3e^-)$

$3(O_2 + 4e^- \rightarrow 2O^{2-})$

$4Fe + 3O_2 \rightarrow 2Fe_2O_3$

b. $2(Fe \rightarrow Fe^{3+} + 3e^-)$

$3(F_2 + 2e^- \rightarrow 2F^-)$

$2Fe + 3F_2 \rightarrow 2FeF_3$

c. $2(Cu \rightarrow Cu^{2+} + 2e^-)$

$O_2 + 4e^- \rightarrow 2O^{2-}$

$2Cu + O_2 \rightarrow 2CuO$

d. $Cu \rightarrow Cu^{2+} + 2e^-$

$F_2 + 2e^- \rightarrow 2F^-$

$Cu + F_2 \rightarrow CuF_2$

7. a. Reactions A and B are both oxidation half-reactions. If one reaction is oxidation, the other must be reduction.

b. Reactions A and B are both reduction half-reactions. If one reaction is reduction, the other must be oxidation.

8. Ionic compounds are always composed of negative and positive ions, not just positive ions nor just negative ions. Electrons are not created or destroyed in normal chemical changes or reactions.

Enrichment

1. The following is a sample answer.

Salt deposits form when a large area of salt water is cut off from the sea. This forms a huge salt flat within a few hundred or thousand years. This salt flat is then covered with sediment and slowly forced underground, where it becomes the mineral *halite* (naturally occurring salt) trapped in a salt dome.

When the ground above the dome becomes more dense than the salt, the dome begins to be forced up through the ground as the ions in the salt are slowly forced past each other under tremendous pressure. In the process, oil and gas may also collect near the dome. These salt domes can be mined in two principle ways:

- The salt dome can be mined in a similar manner to coal and other minerals by simply digging tunnels into the salt and leaving some salt behind to act as pillars to hold the roof up. The danger in this method is that over a period of time (100 years) the tunnels can close themselves off due to the creeping of the salt. In addition, anything metal that is not aluminum will oxidize very quickly once brought out of the mine.

- The salt can be removed as brine. (This is also how salt is obtained from salt water.) In this process water is forced into the salt and the salt dissolves easily because of its soluble ionic properties. The resulting solution called brine is pumped back to the surface. The water is evaporated by a variety of means. After purifying, salt remains.

  Because ionic solutions are good conductors of electricity, a charge easily passes through the brine solution. This makes corrosion a problem with this method as well.

2. The following is a sample answer.

Minerals must have four characteristics:

- They have a regular crystal structure.
- They have the same composition no matter where they are found.
- They are found in nature (not synthetic).
- They are composed of non-living material.

Minerals can be classified according to their colour, cleavage, hardness, and lustre. The colours of minerals are often due to the presence of transition metals in the structure. For ionic minerals, the hardness is determined by the degree of ionic character (how big a difference there is between the electronegativities of the cation and anion).

Another classification scheme often used is classifying minerals based on the elements that make up the crystal and by the shape of the crystal. The classifications include: the elements themselves, carbonates, halides, oxides, phosphates, silicates, sulphates, and sulphides. The ionic minerals in this group are the carbonates, halides, oxides, phosphates, sulphates, and sulphides. Except for the silica group, part of the silicate class, silicates are also ionic. The silica group is the group containing silicon dioxide (present in quartz).

When a crystal is broken, it always breaks along planes that maintain the original crystal shape of the mineral. This basic shape is determined by the way the formula units of the mineral best pack together. The size and charge of the ions making up the formula unit of the crystal determine the way the formula unit packs together.

3. The following is a sample answer.

A fertilizer is any substance added to the soil that helps plants grow. The three main elements contained in fertilizers are nitrogen, phosphorus, and potassium. Since these are the most important elements, a code called the N-P-K code is used to rate fertilizers. The general rating is done by writing the percent by mass of nitrogen, phosphorus, and potassium present in the fertilizer. For example, a code that is written 15-27-2 means there is 15% nitrogen by mass, 27% phosphorus by mass, and 2% potassium by mass.

Usually nitrogen comes in the form of nitrates or ammonia, but urea is often used as well. All the nitrogen compounds must be converted to the nitrate ion (this process is called *fixing*) which is used by plants to build new plant material as they grow.

Humans consuming plants grown in soil having too many nitrates can develop various health problems. In addition, because they are so water-soluble, nitrates can often be washed away. Thus, other forms of nitrogen are often used to maintain a steadier supply of nitrates to the plants.

Phosphorus usually comes in the form of P_2O_5 or in a phosphate form, often combined with calcium or ammonium ions. Ammonium dihydrogen phosphate and ammonium hydrogen phosphate are very popular because their N-P-K code is 11-48-0 and 18-46-0 respectively.

Hydrogen phosphate and dihydrogen phosphate ions are the ones that are used by plants. Phosphorus is necessary to plants because it is used to make DNA. DNA codes the correct sequence of amino acids, the building blocks of plant proteins. Phosphorus is also present in adenosine triphosphate (ATP) which is necessary for plant metabolism.

Too much phosphorus in the soil can cause environmental damage, especially water pollution. Phosphates are not very water-soluble and stay in the soil. If the acidity of the soil is not nearly neutral, the phosphates can bind ionically to cations such as aluminum, iron(III), or calcium ions, which keeps them fairly insoluble.

Potassium usually comes in the form of KCl or K_2SO_4, but for plants that are sensitive to chloride, KNO_3 is used. Potassium nitrate is not as commonly used because it is more expensive.

Potassium is needed by plants to help regulate water balance, to transport iron ions, and to activate some plant enzymes. However, it is easily removed from the soil and must constantly be replenished. This is not a big problem with grain crops, but is more of a problem when the entire plant is harvested, such as with hay. Low levels of potassium can severely limit crop growth.

Since each type of plant requires different amounts of nitrogen, phosphorus, and potassium, and because there are many different soil conditions, many N-P-K formulas exist. As well, depending on the plant, climate, and environment, different forms of nitrogen, phosphorus, and potassium must be used in the fertilizer.

Section 3: Activity 1

1. The other seven elements that form diatomic molecular compounds are the following:

   - hydrogen, H_2
   - fluorine, F_2
   - bromine, Br_2
   - astatine, At_2 (rarely considered)
   - nitrogen, N_2
   - chlorine, Cl_2
   - iodine, I_2

2. a. Nonmetallic elements form molecules.

   b. A covalent bond forms between atoms in a molecular element or compound. The covalent bond can be polar or non-polar in a compound.

3. a. Chlorine and oxygen form diatomic molecules because each atom has a very strong desire to complete its octet. For example, when one chlorine atom forms a bond with another chlorine atom, the octet for both atoms is completed through the sharing of two bonding electrons.

   b. Lewis models (electron dot diagrams) were used to show how molecular elements form.

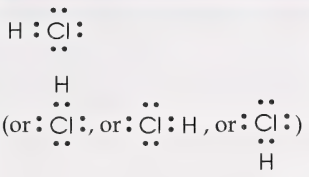
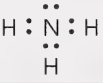
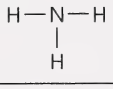
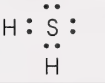
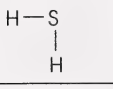
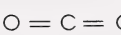
4. a. A structural diagram illustrates the way atoms bond in molecules. It only shows bonding electrons by means of dashes (bonds) between atoms and does not show lone pair electrons. Each dash or line represents a shared pair (2) of bonding electrons.

   b. A structural diagram of F_2 would look like this:

F — F
↑
bond
(shared pair of electrons)

5. **Textbook question 35:**

Note: Usually one answer will be given. But, as you can see, several ways of writing the answer are possible, as long as the octet rule is followed.

	Electron Dot Diagram	Structural Diagram
a. HCl is hydrogen chloride.	 (or)	
b. NH_3 is ammonia.		
c. H_2S is hydrogen sulphide.		
d. CO_2 is carbon dioxide.		

Textbook question 33:

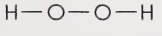
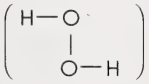
H—H—S is incorrect because the middle hydrogen is bonded to two atoms. Since hydrogen has only one bonding electron, it can only make one bond. The correct arrangement would be .

Textbook question 34:

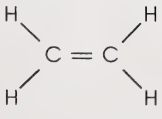
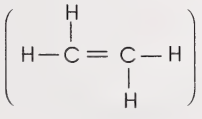
CH_3OH is used because it shows that there is one hydrogen attached to the oxygen and three hydrogens attached to the carbon. In the formula CH_4O, it appears that all four hydrogens are attached to the carbon, as well as the oxygen, which is not possible.

Textbook question 36:

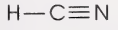
a. H_2O_2

 **or,** 

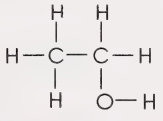
b. C_2H_4

 **or,** 

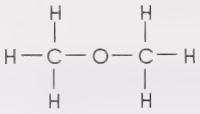
c. HCN



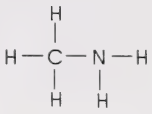
d. C_2H_5OH



e. CH_3OCH_3



f. CH_3NH_2



6. a. Two details Lewis models are able to indicate are as follows:

   - identifies which electrons are involved in bonding
   - shows how many bonds an atom can make

   b. Two details Lewis models do not indicate are as follows:

   - what an orbital or atom looks like
   - where electrons are actually found in an atom

7. When a Lewis model becomes a structural diagram, the lone pairs are not shown and the shared electron pairs become a straight line.

8. a. Bonding electrons make the bond.

   b. Two electrons are involved in each bond.

   c. Valence orbitals overlap when bonded.

   d. The total number of valence electrons accessed by each bonded atom is eight.

   e. Covalent bonds are formed.

9. Several answers could be given. Here is one example.

   Suppose you and your friend shared a chocolate bar that had six sections. If you each had three sections, that would be equal sharing. If you had two sections and your friend four sections, that would be unequal sharing – but it is still sharing.

10. The atom with the largest electronegativity creates the more negatively-charged end of a polar covalent bond. The shared electrons spend more time around the more electronegative atom. The greater the difference in electronegativities, the more polar the bond.

    Example:

    H — F
    2.1 4.0
    + → −

11. a. A Lewis model of CCl_4 would look like the following:

    A Lewis model of NI_3 would look like the following:

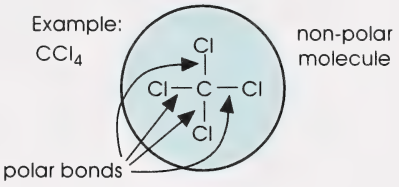
    b. Both CCl_4 and NI_3 have polar covalent bonds.

    c. The CCl_4 is symmetrical, while NI_3 is not as symmetrical.

12. a. The two factors that could explain whether a molecule will be polar or non-polar are as follows:

- the polarity of the bonds in the molecule
- the shape of the molecule

b. If the molecule is symmetrical (balanced on all sides), the molecule will be non-polar even though the individual bonds are polar.



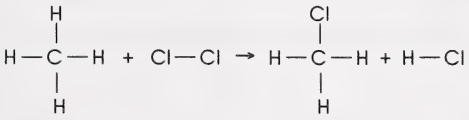
Section 3: Activity 2

1. Your data for Investigation 8.2: Molecular Models may look like the following:

a. **Chemical Equation**

$$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$$

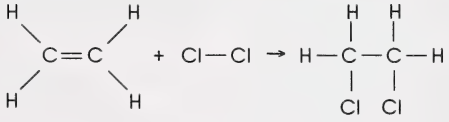
Structures



b. **Chemical Equation**

$$C_2H_4 + Cl_2 \rightarrow C_2H_4Cl_2$$

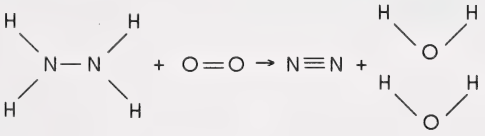
Structures



c. **Chemical Equation**

$$N_2H_4 + O_2 \rightarrow N_2 + 2\,H_2O$$

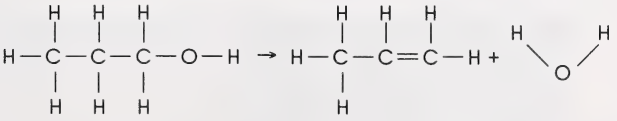
Structures



d. **Chemical Equation**

$$CH_3CH_2CH_2OH \rightarrow CH_3CHCH_2 + H_2O$$

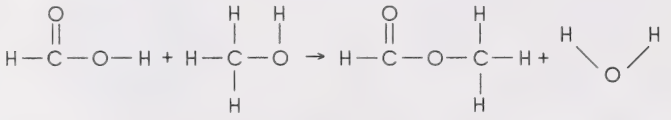
Structures



e. **Chemical Equation**

$$HCOOH + CH_3OH \rightarrow HCOOCH_3 + H_2O$$

Structures



2. a. The number of atoms, and therefore mass, is always conserved in a chemical reaction.

   b. All the atoms together with single bonds to ensure all the atoms would fit as part of the molecule.

   c. A triple bond would be represented by three molecular bond pieces like springs. On paper, this is represented by three lines.

3. Yes, the method was as logical, consistent, and simple as possible because it followed the laws of conservation, and each atom and bond was manipulated as little as possible to create the products.

4. Your data table and possible evidence should be similar to the following:

Substance	Observations
Cyclohexane	no change observed; colour still present
Cyclohexene	the bromine colour disappeared
Corn oil	colour disappeared
Paint thinner	no change observed; bromine colour still present
Olive oil	colour disappeared

5. Whenever the bromine disappeared, it meant that double bonds were present and that the bromine reacted with the double bonds. When only a little of the bromine disappeared, it meant only a few double bonds were present. If the reaction were left longer, most likely all the bromine would have disappeared. Knowing this, any of the compounds where the bromine disappeared contained double bonds. According to this data, the olive oil and corn oil contained some double bonds. The other compounds did not contain double bonds.

6. a. and b. Your data table should look like the following:

Substance	Observations
Cyclohexane	no change observed; colour still present
Cyclohexene	the bromine colour disappeared
Corn oil	colour disappeared
Paint thinner	no change observed; bromine colour still present
Olive oil	colour disappeared

7. Whenever the bromine disappeared, it meant that double bonds were present and that the bromine reacted with the double bonds. When only a little of the bromine disappeared, it meant only a few double bonds were present. If the reaction were left longer, most likely all the bromine would have disappeared. Knowing this, any of the compounds where the bromine disappeared contained double bonds. According to this data, the olive oil and corn oil contained some double bonds. The other compounds did not contain double bonds.

8. a. Because the bromine did not disappear, bacon fat contained no or very few double bonds.

   b. Bacon fat (a saturated fat) is considered more of a health risk than unsaturated fats such as corn oil or olive oil because it is better able to stick to the walls of blood vessels. Since saturated fats are less reactive, they are harder for the body to react with and remove.

9. a. The rule that is broken most often in the Lewis model presented is the octet rule. Many molecules do not have eight valence electrons around each atom. Another limitation is that the electrons are constantly in motion so that they are not really attached to a particular atom as shown in these models. Instead, they can move from atom to atom within the molecule if necessary.

   b. This does not mean the rules of bonding are poor. It just means that the rules can be applied successfully to simple situations. If more complicated bonding situations arise, a more extensive model is required.

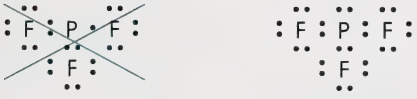
Section 3: Follow-up Activities

Extra Help

1. a. O_2

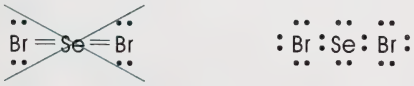
A double bond is formed to satisfy the octet rule.

b. PF_3



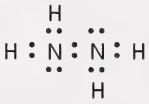
P is missing some electrons.

c. $SeBr_2$



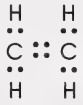
You don't mix structural formulas with Lewis models.

d. N_2H_4



The model is correct.

e. C_2H_4



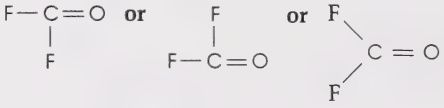
The model is correct.

f. $COCl_2$

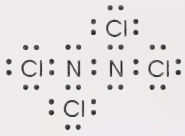
The model is correct.

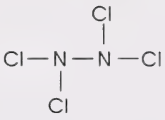
2. a. CI_4

b. COF_2



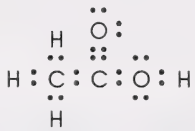
c. N_2Cl_4

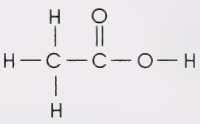




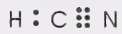
d. C_2H_2

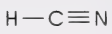
e. CH_3COOH





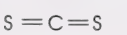
f. HCN





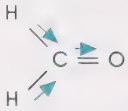
3. The arrows on the structures show the polarization direction of the electrons in each bond.

a. CS_2



CS_2 is non-polar.

b. H_2CO

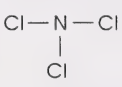


H_2CO is polar.

c. SeF_2

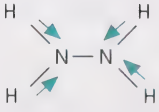
SeF_2 is polar.

d. NCl_3



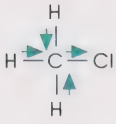
NCl_3 is polar. It is polar because of the unseen lone pair electrons which would be on the top of the structure, if shown.

e. N_2H_4



N_2H_4 is non-polar.

f. CH_3Cl



CH_3Cl is polar.

4. The three substances in the list that do not obey the octet rule are: XeF_6, NO_2, and PCl_5.

Enrichment

1. Composite materials consist of fibres of such substances as glass, graphite, or synthetic fibres embedded in a resin or plastic. Their most important properties are that they are light, flexible, and strong because of the strong covalent bonding that is present in long chains within the molecules. Because of their electron stability composites do not corrode. This makes them valuable replacements for metals.

   The way in which the composites are constructed also helps the composite material from breaking. The composite fibres overlap each other in a criss-cross pattern. When struck with a blow or sharp object, the energy from the impact is absorbed along the fibres, dissipating the energy in every direction. This helps give the composite its strength and allows it to absorb vibrations well. The resin also contains covalent bonds and helps adhere the fibres together.

   One of the most important components of the strongest composites is Kevlar® which is manufactured only by DuPont Canada Inc. Its formula and how it is made is a very carefully guarded secret because of its unique properties.

   Many composites, however, can even be made from such things as recycled plastic. This makes these composites very cheap to make.

   These properties make composites useful for things such as sports equipment, artificial limbs, automobile parts, satellites, protective equipment, heat-resistant clothing, gas tanks, and even airplanes. In fact, during the 1991 Persian Gulf war, one company in Calgary was contracted to build the CF-18 jet fuselages out of composites because they were stronger and lighter than the metal fuselages being used in other planes. This meant the planes could carry more fuel and travel further distances.

2. Ceramics are usually made of a clay base consisting of silicon dioxide or other oxide where the molecules are covalently bonded to one another in a regular, but complex crystal structure. This makes them hard, unreactive, and able to withstand high temperatures before melting. They resist corrosion very well and are excellent electrical insulators because covalent bonds do not allow for easy electron transfer between its molecules. Some of the newer ceramics are also very shatter-resistant because of the way in which the atoms are arranged in the compound.

   When being formed, almost all ceramics are heated to high temperatures and then cooled. The way in which they are heated and cooled, as well as the type of compound added to the ceramic, allows for a wide variety of ceramic compounds.

   Because of their strong bonds, ceramics are being used more and more in place of metals. They are stronger, more rigid, and able to resist higher temperatures. In fact, silicon nitride, a special ceramic compound, has such excellent properties it is thought that one day it may replace the engines in various machines such as automobiles. This would create a better running engine because the engine could operate at a higher temperature and would therefore be more efficient.

   A problem with ceramics is that all the air bubbles must be removed from it as it sets. This is because the air bubbles create irregularities in the crystal structure, greatly reducing the ceramic's strength. As technology improves, however, the strength and resistance of ceramics increases.

   Modern ceramics are also used in artificial body parts, some automobile springs, and in high temperature areas such as ovens and the nose cone of the space shuttle.

3. To determine the empirical molecular formula (the simplest ratio in which the atoms combine) of a molecular compound, a scientist needs to know the molecule's formula mass and the percent composition of each element.

   To find the molar mass of a molecular compound, a mass spectrometer is used. In the mass spectrometer, a small sample of the compound is vapourized. A beam of electrons then passes through the vapour, breaking it into many charged pieces, depending on the strength of the bonds in the molecule. The charged pieces pass through an electric field and are bent by it. Because of their mass, the heavier molecules will go further before they strike the plate that records their impact, while the light ones will bend very quickly. This is similar to an automobile. A small automobile struck from the side by another car would have a quicker, greater veering than a large truck hit by the same car going the same speed.

   The pattern in which the charged molecular parts strike the plate creates a mass spectrograph printout. If there are no isotopes present, the peak with the highest mass is the molar mass of the molecule. The other peaks are used by scientists to help determine the structural formula of the compound. The large peaks indicate that these molecules are fairly well bonded together (stable) and/or there are a large number of them present in the molecule.

   Once the molar mass has been determined, another sample may be burned in a combustion analyser. This is especially useful for organic molecules.

   A combustion analyser works by burning a known mass of sample in the presence of oxygen. The carbon in the sample reacts with the oxygen to produce carbon dioxide, and the hydrogen reacts with the oxygen to produce water. If nitrogen is present, oxides of nitrogen will also be produced. The vapour products then pass through a series of absorbers that collect each oxide one at a time. By noting the mass increase in each absorber, the scientist can determine the amount of each element present. The amount of oxygen in the sample is determined by the amount of mass missing when all the other elements are added up.

   For example, if a 1.50 g (3.26×10^{-2} mol) sample of C_2H_6O were burned, the following products would be produced:

   - 2.87 g (6.51×10^{-2} mol) of CO_2
   - 3.52 g (0.195 mol) of H_2O

   Since the number of moles of carbon is the same as the number of moles of carbon dioxide, the 3.26×10^{-2} mol sample of C_2H_6O contained 6.51×10^{-2} mol (0.782 g) of carbon. Likewise, there would be 0.197 g of hydrogen present. The rest of the sample would be oxygen.

   Once these calculations are done, the percent mass of each element can be found and the molecular formula determined in the following manner.

$$\% \text{ H} = \frac{0.197 \text{ g}}{1.50 \text{ g}} \times 100\% = 13.1\%$$

$$\% \text{ C} = \frac{0.782 \text{ g}}{1.50 \text{ g}} \times 100\% = 52.1\%$$

$$\% \text{ O} = 100\% - 52.1\% - 13.1\% = 34.8\%$$

By assuming one mole of sample (46.08 g) is present, you can calculate the number of moles of each element present.

$$n_H = \frac{m}{M} = \frac{0.131 \times 46.08\ g}{1.01\ g/mol} = 5.98\ mol = 6\ mol\ H$$

$$n_C = \frac{m}{M} = \frac{0.521 \times 46.08\ g}{12.01\ g/mol} = 2.00\ mol = 2\ mol\ C$$

$$n_O = \frac{m}{M} = \frac{0.348 \times 46.08\ g}{16.00\ g/mol} = 1.00\ mol = 1\ mol\ O$$

Therefore one mole of the sample would contain 6 mol H, 2 mol C, and 1 mol O which means its empirical molecular formula would be C_2H_6O.

Section 4: Activity 1

1. a. Ice melting in a glass is an endothermic reaction. Bonds are broken.

   b. Condensing steam from hot soup is an exothermic reaction. Bonds form.

   c. Ripping a paper bag is an endothermic reaction. Bonds are broken.

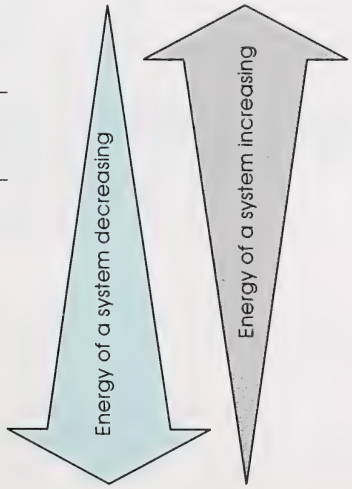
   d. Making dry ice is an exothermic reaction. Bonds form.

   e. Breaking glass is an endothermic reaction. Bonds are broken.

   f. Water vapour condensing on grass as dew is an exothermic reaction. Bonds form.

2.

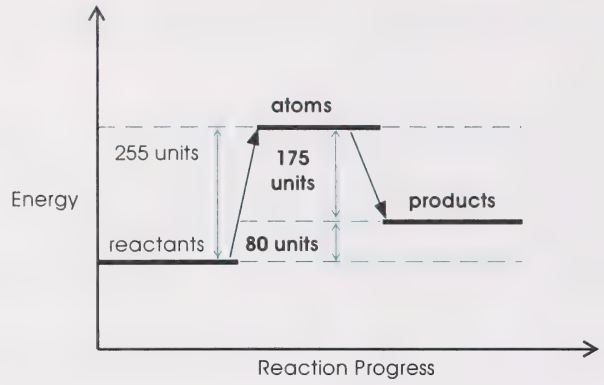
- **exothermic** change
- **forming** bonds



- **endothermic** change
- **breaking** bonds

3. You have to do work in order to overcome the attractive forces that exist within the molecule between one atom's electrons and the other atom's nucleus.

4. a.



b. According to the graph, 255 units of energy were added. If 175 units were released, that leaves 80 units (+ 255 units – 175 units = + 80 units) left over.

c. Since more energy was absorbed (255 units) than lost (175 units), the overall reaction was endothermic.

or,

Since more energy was required to break the reactant bonds than was released in the formation of product bonds, the reaction was endothermic.

5. a. The reaction is endothermic.

b. The reaction is exothermic.

c. The reaction is endothermic.

d. The reaction is exothermic.

e. The reaction is endothermic.

6. If the energy term is written on the left side of the chemical equation, the process is endothermic. If the energy term is written on the right side of the equation, the process is exothermic.

7.

Weak Bonds	Strong Bonds
• bonds between solid molecules • bonds between liquid molecules	• covalent bonds within molecules • ionic bonds within solid crystals

Section 4: Activity 2

1. a. Some possible situations when friction is desired are given in the following list:

- moving from place to place
- making glue hold
- helping you turn while moving
- using plastic wrap
- keeping objects on a slope
- keeping knots together
- using sandpaper

b. Situations when friction is not desired include the following:

- flight – Friction causes drag.
- cooking – Friction makes things stick.
- sports events such as skiing, skating, rowing, etc. – Friction lowers speeds.
- moving engine parts – Friction causes engine wear.
- moving heavy objects – Friction makes it harder to push or pull objects across a surface.

2. a. Some examples of ways you could minimize friction are the following:

- Add ball bearings between the surfaces.
- Treat the surface with a non-stick coating.
- Add powdered graphite to the surfaces.
- Levitate a surface much as a hovercraft does.
- Add a liquid such as oil or water between the surfaces.

b. Some ways you could increase friction are the following:

- Add glue or other sticky substance.
- Add sandpaper or other rough surface.
- Increase the mass of the object without increasing the surface area of contact.

3. Remember that energy is absorbed when bonds break and energy is released when bonds form. When the weak forces of attraction (bonds) form between the hands, energy is released in the form of heat. The movement of your hands provide the work to break bonds, and the cycle continues. If you press your hands closer together, the opposite charges move closer together. The stronger forces of attraction that result lead to more energy being involved, which in turn results in more heat.

4. The three types of intermolecular forces are the following:

- London (dispersion) forces
- dipole-dipole forces
- hydrogen bonding

5. a. Intermolecular forces are weak because the **distance** between the electron of one molecule and the **nucleus** of the other molecule is **greater** than the distance between the **electrons** and nuclei within the molecule.

b. The forces within a molecule are called intramolecular forces. These forces (involving sharing of electrons) cause the formation of **covalent** bonds.

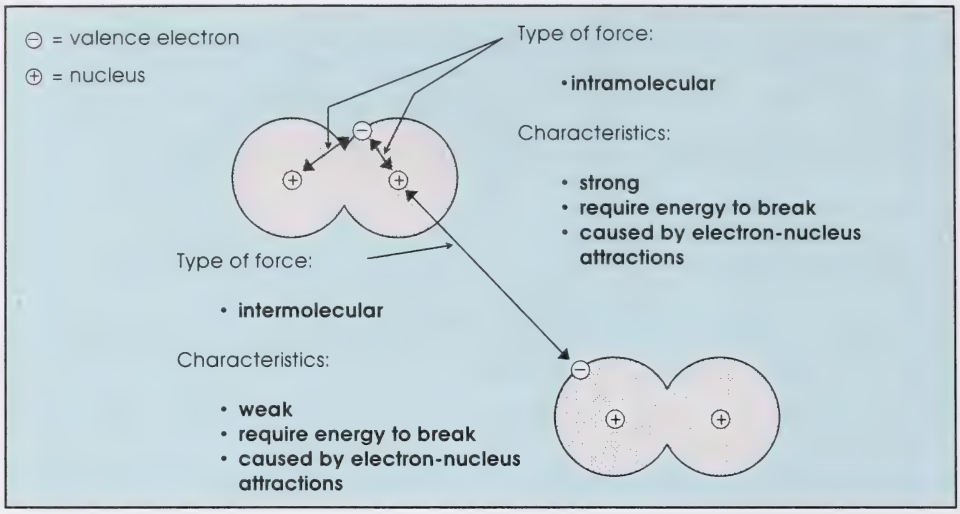
6. a. Two main factors that increase the strength of the intermolecular forces are the following:

- the size of the molecule (which is directly related to the number of electrons and protons in the molecule)
- the polarity of the molecule (The larger the molecule, the greater the intermolecular forces. The more polar the molecule, the greater the intermolecular forces.)

b. Of these two factors, the one that has the greatest effect on the melting and boiling points of substances is the size of the molecule.

7. One way to indirectly determine the strength of an intermolecular force is to look at the molecule's **boiling point** or **melting point**.

8.



9. Intermolecular forces are also involved when dealing with solubility. When determining the solubility of two substances, a general rule is that **polar** substances will mix with or dissolve **polar** substances while **non-polar** substances will mix with or dissolve **non-polar** substances. This is summarized by the three word rule: **like dissolves like**.

10. Typically, if two molecules have the same number of electrons, the more **polar** molecule will have the higher melting and boiling point.

11. A data table for testing molecular polarity may look as follows:

Substance	Observations
Water	stream bends toward balloon
Alcohol	stream bends toward balloon
A light vegetable oil	stream shows no change
Vinegar	stream bends toward balloon

12. The substances that appeared to be polar are the water, alcohol, and vinegar. The substance that appeared to be non-polar was the vegetable oil. The polar substances were attracted to the balloon because the balloon was charged.

13. a. The results would be the same.

    b. Since the molecules tested are liquids, they can easily slide past each other. Therefore, when an oppositely charged object is brought near, the molecules will just re-orient themselves so the opposite charge is still facing the object and attraction occurs.

14. The vinegar could give misleading results because it is a mixture containing mostly water, which is polar. If the vinegar was dissolved in a non-polar substance, the results could be tested more reliably. The solvent would then have no effect on the result.

15. a. Both forces are due to electron-nuclei attraction.

    b. The differences are shown in the following table:

Intermolecular → Weak Bonds	Intramolecular → Strong Bonds
• between molecules	• within molecules
• small energy change when broken or formed	• large energy change when broken or formed
• creates mostly physical properties (melting point, boiling point, surface tension, ease of vapourization)	• creates mostly chemical properties
• distance between charges is larger	• distance between charges is smaller
• polarity affects strength	• difference in electronegativity affects type

Section 4: Activity 3

1. The biggest problem a chemist faces is that the atoms and molecules are too small to actually be seen.

2. a. The microscope would be least beneficial because it does not help a chemist see what is happening at the molecular level.

   b. The computer would be the most beneficial because it is so versatile and can be connected to almost any instrument. It can quickly do much of the repetitive work or extremely difficult calculations for the chemist.

3. The microscope and the computer do not directly interact with the molecules being studied.

4. As technology progresses, smaller and smaller particles may be detected.

5. Being able to move atoms with the scanning tunnelling microscope allows the following:

   a. In new drug manufacturing, chemists can build new drugs almost atom by atom.

   b. In genetic engineering, geneticists can work atom by atom to modify certain parts of the DNA structure in the fight against various diseases.

   c. Chemists actually observe how bonding occurs and how it responds to various changes that may occur.

6. A person may wish to use a scanning tunnelling microscope for such things as the following:

   - designing minute computer chips where only one or two atoms of impurity are added to the silicon
   - carrying out chemical reactions at the atomic level rather than the mole level
   - detecting extremely small amounts of impurities in a crystal
   - determining molecular structures

7. Being a metalloid, silicon only conducts electricity slightly when impurities are added. It also has covalent bonds, which makes it strong.

8. Technology allows scientists to use new techniques that allow them to look at molecules in a different way or to create pictures that are more easily visualized than previously. It also gives them more control over the molecules they are studying.

9. a. Tennis racquets, skis, and bicycles would best be made of a composite.

   b. A nose cone of the space shuttle would best be made of a ceramic.

   c. Engine parts of an automobile would best be made of a ceramic.

   d. A body part of an automobile would best be made of a composite.

   e. Tires would best be made of a composite.

   f. Ovens would best be made of a ceramic.

   g. Protective sports equipment would best be made of a composite.

Section 4: Follow-up Activities

Extra Help

1. a. Popping a balloon is an endothermic reaction. Intermolecular bonding is involved.

   b. Putting hot sodium in chlorine gas is an exothermic reaction. Intramolecular bonding is involved.

   c. Making liquid ammonia from gaseous ammonia is an exothermic reaction. Intermolecular bonding is involved.

   d. Digesting food is an exothermic reaction. Intramolecular bonding is involved.

   e. A plant growing in sunlight is an endothermic reaction. Intramolecular bonding is involved.

   f. Crushing a sugar cube is an endothermic reaction. Intermolecular bonding is involved.

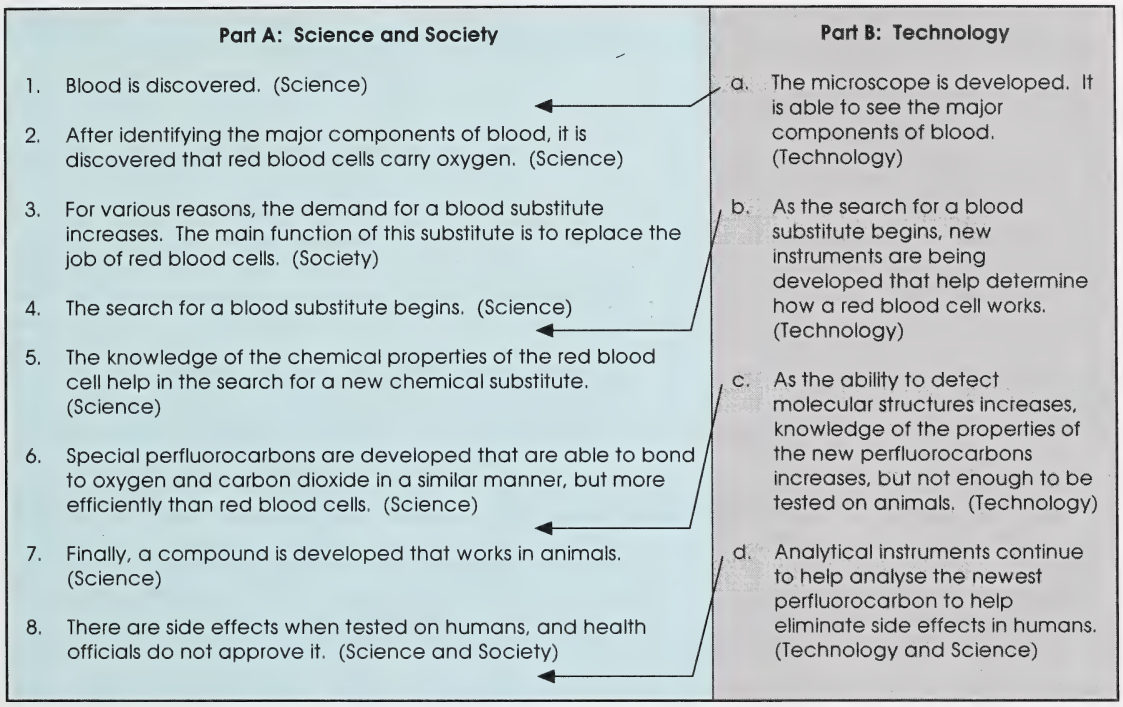
2. When a bond in a molecule is broken, the final energy of the product is higher.

3. If the polarity of a molecule increases, its melting point will increase because of greater intermolecular forces.

4. To determine whether a molecule is polar, hold a charged object near it. If attraction occurs, the molecule is polar.

5. The only activity that does not usually involve computers is sleeping, but this may also change in the future.

6. The correct order is illustrated as follows. The proper sequence of events is **1-a-2-3-4-b-5-6-c-7-8-d**.


Part A: Science and Society
1. Blood is discovered. (Science)
2. After identifying the major components of blood, it is discovered that red blood cells carry oxygen. (Science)
3. For various reasons, the demand for a blood substitute increases. The main function of this substitute is to replace the job of red blood cells. (Society)
4. The search for a blood substitute begins. (Science)
5. The knowledge of the chemical properties of the red blood cell help in the search for a new chemical substitute. (Science)
6. Special perfluorocarbons are developed that are able to bond to oxygen and carbon dioxide in a similar manner, but more efficiently than red blood cells. (Science)
7. Finally, a compound is developed that works in animals. (Science)
8. There are side effects when tested on humans, and health officials do not approve it. (Science and Society)
Part B: Technology
a. The microscope is developed. It is able to see the major components of blood. (Technology)
b. As the search for a blood substitute begins, new instruments are being developed that help determine how a red blood cell works. (Technology)
c. As the ability to detect molecular structures increases, knowledge of the properties of the new perfluorocarbons increases, but not enough to be tested on animals. (Technology)
d. Analytical instruments continue to help analyse the newest perfluorocarbon to help eliminate side effects in humans. (Technology and Science)

Enrichment

1. DNA fingerprinting was developed from a basic understanding of chromatography. In chromatography, molecules are dissolved in a solvent and passed through a certain medium that soaks up the solvent. The rate at which the molecules move depends on how strongly they are attracted to the solvent and the medium. This in turn depends on such things as molecular polarity, molecular size, ability to conduct electricity, and so on. Notice that these are all properties of the intermolecular forces of molecules. Generally, the more the molecules are attracted to the solvent, the more the intermolecular forces are alike and the faster the molecules pass through the testing device.

   In DNA fingerprinting, scientists break apart the nucleus of cells and extract the DNA. The scientists then use a technique called *electrophoresis* to separate the proteins in the DNA from each other.

   In electrophoresis, the scientist pours hot liquid ranging in pH from seven to nine over a glass plate. The liquid contains an electrolyte to help it conduct electricity. When cool, the liquid forms a gel that will be the medium through which the DNA proteins will travel. This gel must be kept cool during the separation process, so the glass is placed on a cooling plate while the experiment is in progress.

   When ready to do the test, the scientist places the unknown sample with some reference samples on the gel and runs an electric current through it. Each protein has a different size, and because of the pH, each protein also has a different charge. The larger the protein and the greater the charge, the more the protein is attracted to the electrodes, so the faster and further it travels on the plate.

After the electrophoresis, the plate is treated with a chemical that causes the proteins to light up when exposed to ultraviolet light. By looking at the plate under ultraviolet light, the scientist is able to see if the unknown sample matches with one of the known samples. Since some proteins are the same, the scientist must be careful to compare only the proteins that are different in each of the known samples.

2. Your answer should be similar to the following.

There are two basic instruments used when testing for drug use in athletes. One of these machines is a gas chromatograph; the other is a mass spectrometer.

In a gas chromatograph (GC), urine or blood samples are vapourized and injected into what is known as a separation column. The column is filled with a substance through which the gas must flow. The rate at which the molecules move depends on how strongly they are attracted to the column material. This in turn depends on the type of intermolecular forces the molecules have. If the intermolecular forces are similar to the material in the column, the molecules will take longer to pass through the column because they will be more attracted to the column material. By measuring the time it takes for the molecules to pass through the column, called the retention time, scientists are able to roughly determine whether or not the substance is an illegal one. (This is done by comparing it to a standard or known sample, in this case the illegal drug.)

If the person being tested has a retention time peak at the same time as an illegal substance, another GC is run using a slightly different column, and another comparison is made. After another positive result, the sample is run through a mass spectrometer.

In the mass spectrometer, a small sample of the compound is vapourized. A beam of electrons then passes through the vapour, breaking it into many charged pieces, depending on the strength of the bonds in the molecule. The charged pieces pass through an electric field and are bent by it.

Because of their mass, the heavier molecules will go further before they strike the plate that records their impact, while the light ones will bend very quickly. This is similar to an automobile. If a small automobile is struck from the side by another car it would veer more than a large truck hit by the same car going the same speed.

The pattern with which the charged molecular parts strike the plate creates a mass spectrograph printout. If there are no isotopes present, the peak with the highest mass is the molar mass of the molecule. The other peaks are used by scientists to help determine the structural formula of the compound. The large peaks indicate that these groups of atoms are fairly well bonded together (stable) and/or there are a large number of them present in the molecule.

By comparing the peaks of the sample with a standard, the tester can determine whether the GC results were because of an illegal substance or because of a substance with similar polarity and intermolecular forces.

A masking agent will give the same or nearly similar GC results as the illegal drug. However, since the masking agent is usually at a much higher concentration, it covers up any slight difference in retention times between the two drugs. Once the sample is tested with a mass spectrometer, the high concentration of the masking agent covers up the drug by making the drug look like small signals, or parts of other signals belonging to the masking agent.

3. Your answer should be similar to the following.

Perfumes consist of three parts:

- an aromatic part called the essential oil
- a fixative
- an alcohol or alcohol/water base which acts as the solvent for these other two components

The essential oil is the part of the perfume that gives the perfume its smell. It can be either synthetically produced or obtained from various plants or parts of plants, the most expensive of which come from flower petals. Other sources include any of the other parts of the plants from the buds to the roots. To remove the oils from the plants, perfume makers use techniques involving differences between the molecular polarities or differences in the boiling points of the oils and the plant materials.

One of the common techniques of oil removal is by steam distillation. In steam distillation, a mixture of plants and water is boiled, sometimes under reduced pressure, causing the intermolecular bonds in the oil to break. The oil molecules proceed as gases into the cooling chamber of the distillation apparatus. Because the oils are made of non-polar molecules and the water is polar, they do not mix. When the oil and water condense, it is very easy to separate the two layers.

Another very common method is to use solvent extraction. In this method the petals are placed in a non-polar solvent. Since the oils are non-polar, they will dissolve in the solvent. This extract is then distilled to remove the solvent. Ethanol is then added to the residue. Because they have similar intermolecular forces, the essential oils dissolve in the ethanol. This time, the ethanol is distilled, leaving the essential oils behind.

A third method is called *enfleurage*. In this method, fat is spread onto glass plates. Flower petals are placed in the fat and pressed between the plates. Because like dissolves like, the oils enter the fat. The fat is then treated with ethanol and the rest of the procedure is done as in solvent extraction.

Once the essential oil is obtained, it is mixed with a fixative and alcohol or alcohol-water mixture. While the fixative may have an odour, usually musky, its primary role is to make the perfume last longer. This is because the fixative has stronger intermolecular forces than the essential oil does which means more energy is required to break the intermolecular bonds to make it evaporate. The alcohol or alcohol-water mixture is added to dilute the other two substances. It evaporates very easily when placed on your skin because of the weaker intermolecular forces. Once the base has evaporated, the perfume is left on your skin to slowly evaporate.

The ratio of essential oil, fixative, and solvent determines the price of the final product. The following table summarizes this information.

Type of Fragrance	Composition	Time It Lasts
Perfume	10%-20% oil in alcohol base	long
Cologne	3%-5% oil in 80%-90% alcohol with the rest water	medium
Eau de toilette	about 2% oil in 60%-80% alcohol with the rest water	short

National Library of Canada
Bibliothèque nationale du Canada
3 3286 50429 0897

Chemistry 20

Student Module Booklet

Module 5

L.R.D.C.
Producer

1993